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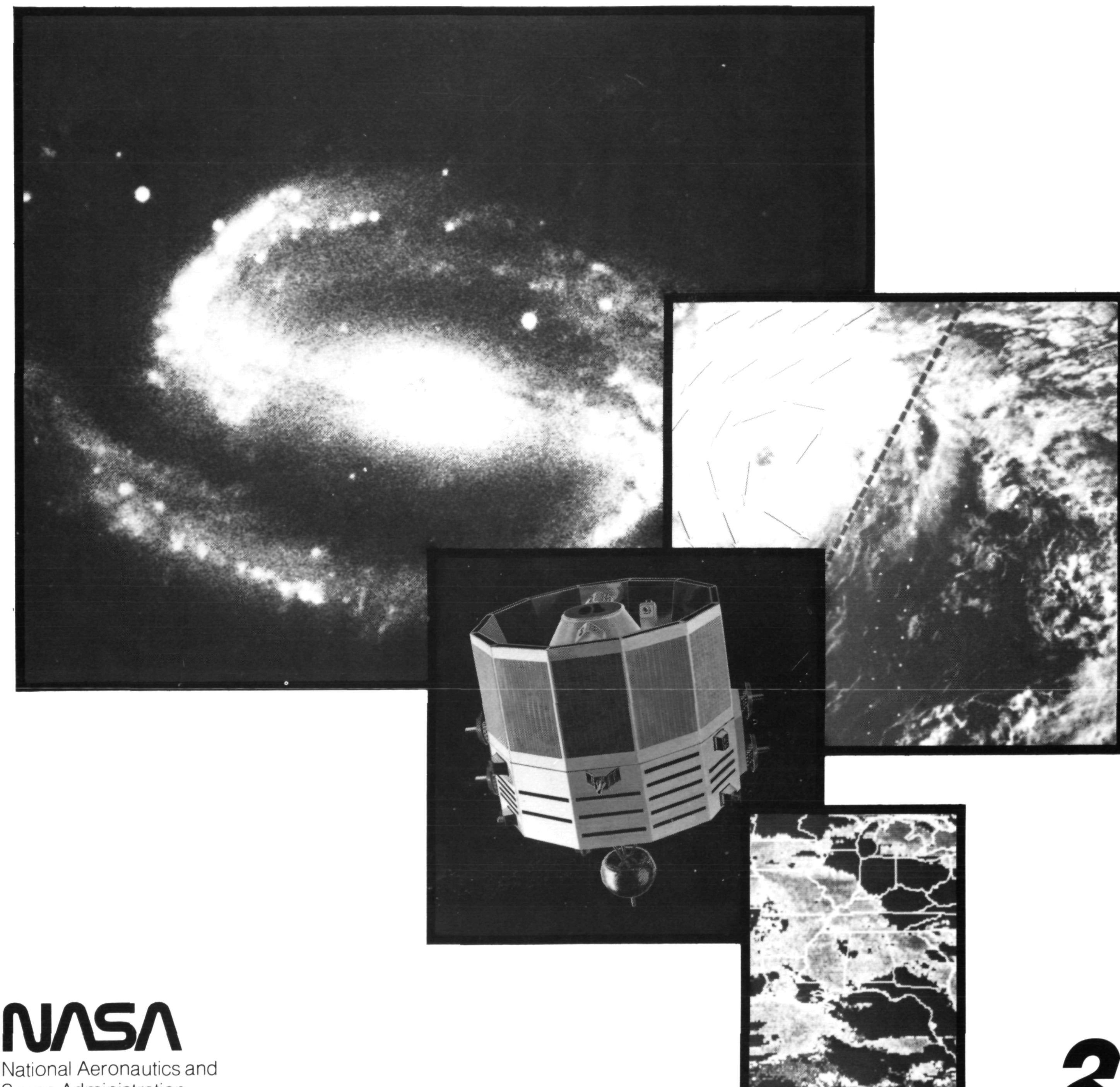
Research and Technology

Fiscal Year 1983 Annual Report



NASA
National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

25
25th Anniversary
1958-1983

FOREWORD

The responsibilities and programs of the Goddard Space Flight Center are the most varied of any NASA center. Ranging from basic research in the space and Earth sciences through the management of numerous flight projects to operational responsibility for the tracking of and data acquisition from NASA's Earth orbiting satellites, the Center's activities present a multifaceted view of a vigorous, dynamic organization. Central to the Center's work is a strong Research and Technology Program particularly in the areas of spacecraft technology, sensor development and data system development, as well as in the basic and applied research in the space and Earth sciences that they support. This report covers the highlights of Goddard's progress in FY 1983 in all these areas.

The point of contact within the Center for this report is Dr. George F. Pieper, GSFC, Code 100 (344-7301), who provided overall editorial supervision. He was assisted by Mr. Paul G. Marcotte, GSFC, Code 400, and Dr. Gerald A. Soffen, GSFC, Code 900. Detailed editorial support and the production of the report were supervised by William W. Cooper, GSFC, Code 251 and Brenda J. Vallette, Engineering and Economics Research, Inc., Beltsville, Maryland.

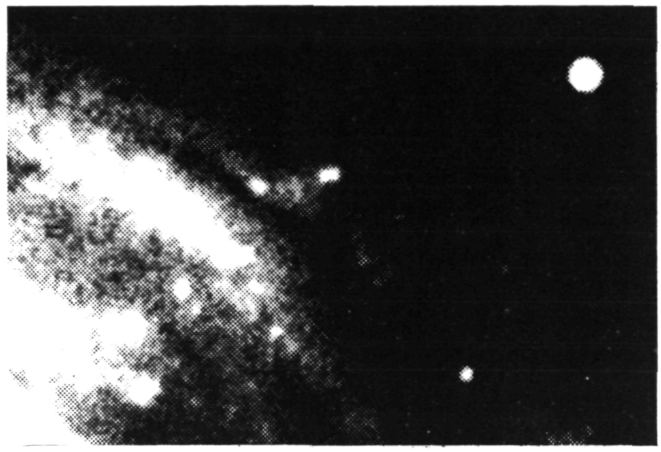
Noel W. Hinners

Noel W. Hinners
Director

CONTENTS

SPACE SCIENCES

The GSFC space sciences activities are directed toward the investigation of the Earth's space environment, the Sun, the solar system, the interplanetary medium, galactic and extragalactic phenomena, and the interrelationships among them. GSFC scientists continued to pursue a wide variety of research studies, data analysis efforts, instrument developments and measurement projects to increase man's understanding of the universe. Major efforts were devoted to the detailed study, analysis, and interpretation of data obtained from a number of space missions.



ASTRONOMY

High Energy Astrophysics

Galactic X-Ray Astronomy

For 12 years Cygnus X-1 was the only X-ray source for which optical measurements of the companion star identified a compact object with mass so large as to require a black hole (i.e., the mass exceeds the limits of any known stable theoretical solutions from which light can escape the gravity of the compact object). This year measurements of the velocities of the companions of two sources in the Large Magellanic Cloud galaxy, LMC X-3 and LMC-1, added them to the category of black hole as a result of the same sort of mass estimates.

These identifications appear to confirm the possibility that a particular X-ray attribute characterizes black holes of stellar size. The HEAO-2 and HEAO-1 data on LMC X-3 and LMC-1 show that their X-ray energy spectra are similar to that of Cygnus X-1 when most bright (i.e., when the luminosity is nearest the luminosities of the LMC sources).

Other sources in our galaxy have similar spectra, and two well known sources also have very fast irregular X-ray changes analogous to those of Cygnus X-1. The GSFC data have identified more Cyg X-1 like spectra, especially among transient sources which brighten for about a month at intervals of many years. Their X-ray spectra are so similar to those with measured black hole masses (and different from those of neutron stars and white dwarfs) that they must be considered as black hole candidates as well.

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X-ray Emission from Active Galactic Nuclei

Active galactic nuclei (AGN, otherwise known as quasars, Seyfert galaxies, BL Lac objects, etc.) are enormously powerful emitters of radiation at all wavelengths from radio waves to X-rays. However, it is expected that the X-ray emission comes from a region most directly associated with generating the observed energy, and thus a detailed study of the X-ray properties of AGN should be especially interesting.

In the last year, several properties of the X-ray emission of AGN have been well established. A detailed study of the X-ray time variability of AGN (based on HEAO-1 data) has shown that contrary to expectation, most of the objects do not vary strongly on short time scales. It had been anticipated that if these objects were black holes radiating at the maximum possible luminosity for their mass (the Eddington limit), most of these objects would show strong variability on time scales from hundreds of seconds to hundreds of minutes. The lack of such variability for almost all of the AGN indicates that either the X-ray emission does not come from near the black hole or that these objects are more massive than arguments based on the Eddington limit would have concluded.

The X-ray spectra of the largest class of AGN (Seyfert galaxies) have shown a remarkable sameness. All of these objects show a smooth power law shape continuum of roughly the same slope in the 5 to 100 keV band. This indicates that whatever physical mechanism is producing the X-rays is independent of the luminosity of the object, and not a function of the age, mass or size of the object. This "universal" X-ray spectral signature of AGN is a unique signature shared by no other class of astronomical object and so is a strong clue to the nature of their X-ray emission process. One physical process which can reproduce this very simple X-ray spectrum requires a relativistic population of electrons very similar to the cosmic rays in our own galaxy. If this hypothesis is correct, then we have a bridge between the exotic conditions near a massive black hole and those in our own relatively normal galaxy.

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Physical Process in High Temperature and Relativistic Plasmas

An important and new astrophysical research topic is opening at the present time, one that involves relativistic and highly magnetized plasmas with large concentrations of electron positron pairs. Theoretical research in this area is applicable directly to the study of such astrophysical objects as gamma-ray burst sources, pulsars, the nucleus of our galaxy and nuclei of active galaxies. We are developing the basic theoretical tools for the study of these systems. Our studies include the processes of pair production and pair annihilation (including stimulated annihilation), bremsstrahlung, Compton scattering, and synchrotron radiation in very strong magnetic fields. We are also investigating acceleration processes by, for example, shocks formed by accretion flows around massive black holes and by neutron star vibrations. Our studies have already shown considerable promise in explaining observed phenomena in gamma-ray bursts, pulsars, the galactic center, and active galaxies. For the galactic center, in particular, we have been able to show that the observed 0.511 MeV gamma-ray line and the continuum above about 0.2 MeV are produced by the same compact object, probably a 200 solar mass black hole.

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Gamma Ray Spectroscopy and Transient Studies

The discovery by B. Schaefer of MIT of an optical flash—occurring 50 years earlier and preserved in archived photographs—from the precise source direction of a 1978 gamma-ray burst has been confirmed with two more events. Optical transients photographed in 1901 and 1944 were recently found in the source fields of two 1979 gamma-ray bursts that were determined with the interplanetary NASA-Goddard/Los Alamos/Franco-Soviet spacecraft network. This collaboration between Schaefer and the burst experimenters is providing additional precise (≈ several arc second) fields to be scrutinized with deep optical searches for evidence of source objects, thus far totally elusive.

A new research concept, also prompted by this discovery, is the development by B. Teegarden and others at Goddard, in collaboration with G. Ricker

of MIT, of a ground-based system with the capability of detecting these flashes in real time. The MIT portion of the system, the Explosive Transient Camera (ETC) is a fly's-eye array of 16 small CCD cameras that will look at ~3 sr with a resolution of ~5 arc min/pixel. The system will be able to detect flashes with a response time of 1 to 2 seconds. GSFC is developing a companion instrument, the Rapidly Moving Telescope (RMT) that will have the capability of acquiring sources detected by the ETC and making accurate measurements of the position and light curve. The RMT will be able to measure point sources to ≈14 mag (1-second exposure) and to determine positions to <1 arc sec accuracy. Eventually it may be upgraded to include a limited spectroscopic capability.

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High Energy Cosmic Rays

Utilizing new observations of the nearby intersellar medium (<500 pc), which point to a hot low-density gas around us, a model for cosmic ray propagation has been developed. The calculations examine the consequences of the solar system being inside a superbubble formed by the sequential supernova explosions as a result of the evolution of the OB-association surrounding the solar system. The model reconciles the observations regarding the high energy anisotropy, the lifetime of low-energy cosmic rays, and the charge composition of cosmic rays.

The highly accurate charge composition data from the Danish-French experiment on the HEAO-3 has allowed the energy dependence of the escape length of cosmic rays from the galaxy to be redetermined by GSFC guest investigators, and this analysis leads to energy distribution of the form E^{-2} consistent with the first order Fermi acceleration in strong shocks in the interstellar medium. This model for cosmic ray propagation has been reconciled with existing electron energy distribution data by requiring the absence of short pathlengths connecting the observation point and the source.

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High Energy Cosmology

In order to solve an esoteric but important problem involving the theory of strong interactions, theoretical physicists have invoked a mechanism involving a newly postulated particle, called the "axion" by Nobel Laureate Steven Weinberg. This particle has rather unique properties. Axions should be produced copiously in the early hot stage of the Big Bang and, indeed, they may account for the "dark matter" or "missing mass" in the Universe. (Dynamical studies of galaxies show that nonluminous matter makes up over 90 percent of the gravitating mass of the Universe, and there are various reasons for believing that the missing mass is not "ordinary" matter but something like neutrinos, axions, etc.). F. W. Stecker and Q. Shafi have developed a theory of galaxy formation for a universe in which axions, in the form of axion clumps or black holes of collapsed axion matter, make up the missing mass of the Universe. Their theory provides a natural way of deriving the basic mass scales and length scales of galaxy clusters in a hierarchial model of clustering from gravitational interactions between clumps or black holes. Galaxies form around clusters of these axionic objects and then take on their unique character owing to the fact that they consist of ordinary matter. This new ABC (axion black hole clustering) scenario for galaxy formation is an example of the exciting theoretical activity going on at GSFC and elsewhere stemming from applying the new advances in high energy physics to the early Big Bang and cosmology in general.

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Infrared and Radio Astronomy

Survey of Submillimeter Wavelength Emission From the Milky Way

The space between stars in our galaxy contains diffuse clouds of ionized, atomic and molecular gas, and cool grains of dust. The dust plays a critical role in establishing the physical and chemical state of the interstellar material, which is both the beginning and the end point of the stellar evolution cycle. The dust absorbs a significant fraction of the stellar radiation emitted by the galaxy and reradiates this energy in the far infrared to submillimeter wavelength spectral region.

We have built the largest balloon-borne submillimeter wavelength telescope yet flown, a 1.2-m diameter Cassegrain system, to survey the galaxy and thus improve our knowledge of both the spatial distribution of interstellar material and of the luminosity sources which heat it. Data from the first two flights reveal bright diffuse emission throughout the inner galaxy, as well as nearly 100 discrete source regions within 3° of the galactic plane. Comparison of these data with the survey of galactic CO conducted by the Goddard Institute for Space Studies shows strong correlation of the dust and molecular gas. Detailed distributions of physical conditions such as temperature and mass column density have been inferred. The dust responsible for the dominant submillimeter emission is found to be associated with the molecular, rather than ionized or atomic gas components of the interstellar medium.

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Key Compound Sodium Hydroxide Found in Interstellar Space

The space between the stars is often comprised of dust grains which shield the environment from destructive high energy photons from nearby stars. Such shielding provides a safe environment for molecular compounds to exist in gaseous form. To date some 52 unique species of interstellar molecules have been found; most have been identified by detecting spectral emission lines, arising because a molecule changes from one rotational energy level to another. Such changes to the gas-phase molecule can be caused by interactions with the local radiation field or by collisions with other molecules, atoms, or even dust grains whose chemical composition is unknown since the solid grains possess no unique spectral signature. The atoms which comprise interstellar molecules include hydrogen, oxygen, carbon, nitrogen, sulfur, and silicon. The chemistry of interstellar molecule formation and the role grains play in molecular synthesis and evolution is the subject of much theoretical discussion.

Recently the first interstellar compound containing sodium, sodium hydroxide (NaOH), was detected (by a Goddard astronomer and colleague) toward the densest region of the giant molecular cloud which surrounds the center of our galaxy. This finding supports a theoretical model that negative hydroxyl radicals may reside on the surface of interstellar grains. Positive sodium ions abound in the interstellar medium; therefore, surface chemistry reactions between the negative hydroxyl radicals on the grains and colliding positive sodium ions may produce the NaOH that has been observed. Thus, although the formation of some of the simpler interstellar molecules can be explained via ion-molecule chemistry in the gas-phase, the detection of NaOH may represent the first evidence for a molecular formation scheme using dust grains.

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Stratospheric Ethane on Jupiter

The measurement of spectral lines of molecular constituents of the upper atmospheres of planets permits the study of constituent abundances, total pressures, local temperatures, excitation conditions and atmospheric chemistry. In regions where total

pressures are low (<10 mbar) very high spectral resolving powers are required to measure line profiles and thus probe directly at infrared wavelengths. Infrared heterodyne spectroscopy offers adequate resolution and sensitivity for such measurements.

The Goddard Space Flight Center Infrared Heterodyne Spectrometer operating near 12 m was used at the McMath Telescope at Kitt Peak National Observatory to measure and study molecular ethane emission features from the stratosphere of Jupiter. Individual molecular emission lineshapes in the ν_9 band were measured at spectral resolving powers of $\lambda/\Delta\lambda \sim 10^6$ and with spatial resolution corresponding to ν 1/20th of the Jovian diameter.

Utilizing temperature profiles obtained from Voyager-1 and -2 data and radiative transfer theory, volume mixing ratio profiles for ethane were obtained at various positions on the planet. The $C_2H_6:H_2$ mixing ratios varied from 1×10^{-6} to 6×10^{-6}, depending on the location on the planet. The measured emission spectra showed variability in the north polar region. Greatest changes occurred within the auroral oval and near the north magnetic pole. These changes can be attributed to either local heating and changes in the temperature profile or to actual changes in the ethane abundance.

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Jupiter's Magnetic Tail Engulfs Saturn

An unusual, and possibly unique, planetary encounter occurs every 20 years when Saturn and Jupiter are aligned with the Sun. Such an alignment took place in 1981 when the Voyager-2 spacecraft was approaching Saturn. During this time, Goddard scientists found that the spacecraft was often engulfed by the long magnetic tail of Jupiter which is blown anti-sunward from the planet by the solar wind. Simultaneous with the local observations of Jupiter's tail, Voyager radio astronomical observations of Saturn showed that the radio source on that planet was turning completely off. This was interpreted as strong evidence that Jupiter's magnetic tail extended all the way to Saturn and that it repeatedly engulfed the planet, shutting off the Saturn radio source by excluding the solar wind energy flow from Saturn's magnetosphere.

Subsequent observations during the Voyager-2 encounter with Saturn have shown that Saturn was also in Jupiter's tail during the encounter itself. This highly unusual situation has permitted direct observation of a planetary magnetosphere undergoing the effects of an immersion into the magnetic tail of another planet. Some of the directly observed effects include enhanced high-energy particle fluxes, an overall inflation and reorientation of Saturn's magnetospheric magnetic field, and the shutting off of the radio source. Further studies will prove useful in the analysis of magnetospheres under highly anomalous conditions.

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Voyager Discovery of Saturn Lightning

One of the unexpected discoveries of the Voyager missions to Saturn was the detection of the radio signatures of lightning. These signatures appeared in the data from the Planetary Radio Astronomy instrument, which is normally used to record magnetospheric radio emissions. The lightning signals came in short bursts every few seconds and covered a wide range of radio frequencies. The bursts occurred in episodes whose regular timing suggested that whatever their source might be, it was circling Saturn's axis about every 10 hr. 10 min. Only two locations in the Saturn system have rotation or revolution periods similar to this. One is in the middle of the B-ring where ring particles orbit Saturn every 10 hr. 10 min., and the other is in the cloud tops at the Equator where high velocity winds cause the clouds to superrotate every 10 hr. 10 min. (Saturn's internal rotation period is about 10 hr. 40 min.).

Initially, investigators ruled out the atmospheric source and concentrated their efforts on a presumed mysterious object in the rings. However, subsequent analysis by Goddard scientists showed that a source in the rings could not explain some of the details of the radio bursts, but an atmospheric storm system spread some 65,000 kilometers around the Equator does. From their analysis, the Goddard investigators were able not only to describe some of the properties of the storm, but they were also able to obtain considerable information concerning the Saturnian ionosphere through which the radio emissions propagate.

Currently, the Goddard team is attempting to compare the lightning observations at Saturn with terrestrial lightning observations in order to further clarify the nature of the storm system on Saturn.

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Visible and Ultraviolet Astronomy

The Eclipsing Binary System Epsilon Aurigae

The eclipsing binary system epsilon Aurigae is one of the most unusual star systems known. The primary star in the system is an F-type supergiant, which means that the star is about the same size as the orbit of the Earth. From the duration of the eclipse, we know that the eclipsing object is really huge; it is as big as the orbit of Jupiter. Yet, even though all observations lead us to believe that the supergiant should be fully eclipsed by the mysterious companion, its light is dimmed to only 50 percent of its uneclipsed brightness. Early in the century, astronomers thought that the companion was a phenomenally large star. It would have to be the largest known star in the galaxy, with semi-transparent outer layers. During eclipse, we would then continue to see the F supergiant through the monstrous companion. Later, the companion was thought to be a thin disk seen nearly edge on. At mid-eclipse, we would then be able to see the "poles" of the primary star extending above and below the companion.

An eclipse of epsilon Aurigae began in early 1982, affording astronomers a chance to observe it with the International Ultraviolet Explorer (IUE). Perhaps a new look at the system in ultraviolet light would help increase our understanding of its nature. A number of groups have been observing the system on a regular basis since the eclipse began, and some interesting results are beginning to emerge. However, it is clear that we are probably a bit optimistic about the changes of the ultraviolet observations revolutionizing our understanding. It is clear that the companion is not a star. What is being argued is whether there is real evidence for a hot star inside the companion. Astronomers at NASA believe that, while there may be a star associated with the companion, it has not yet been proven conclusively. The companion appears to be an edge-on disk that contains enough material so that it is opaque. The disk, in turn, is surrounded by cool "atmosphere" of plasma and perhaps some fine dust grains. Near the beginning of the eclipse, we viewed the supergiant through this "atmosphere," at which time we could see its influence in the total light from the system. When the eclipse is complete in 1984, the IUE results will have added new and important pieces in the epsilon Aurigae puzzle. It remains to be seen whether these pieces will finally let us see the true nature of this enigmatic object.

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The Local Interstellar Medium

According to recent results from the International Ultraviolet Explorer (IUE), the solar system is embedded in a partially neutral, interstellar cloud. Near the Sun, the gas comprising the cloud had a temperature of about 10,000 to 15,000°K with a moderately low density (about 1 atom/cc). This cloud is no larger than several parsecs (some 20 to 30 light

years) in size. The density within the local cloud is not uniform and appears to become more dense in the direction of the star Fomalhaut. This partially neutral cloud is completely embedded in a very hot, low density plasma with a temperature of some hundreds of thousands of degrees Kelvin and a density of only about one atom per 100 to 1000 cc. The hot plasma appears to extend a few hundred parsecs in most directions. The Sun is moving through the local cloud at the velocity of 20 km/sec. In about a hundred thousand years, the solar system will emerge from this cloud into the hot plasma. The effect on the Earth's climate of our journey through this cloud of fluctuating densities may be only remotely speculated at the moment.

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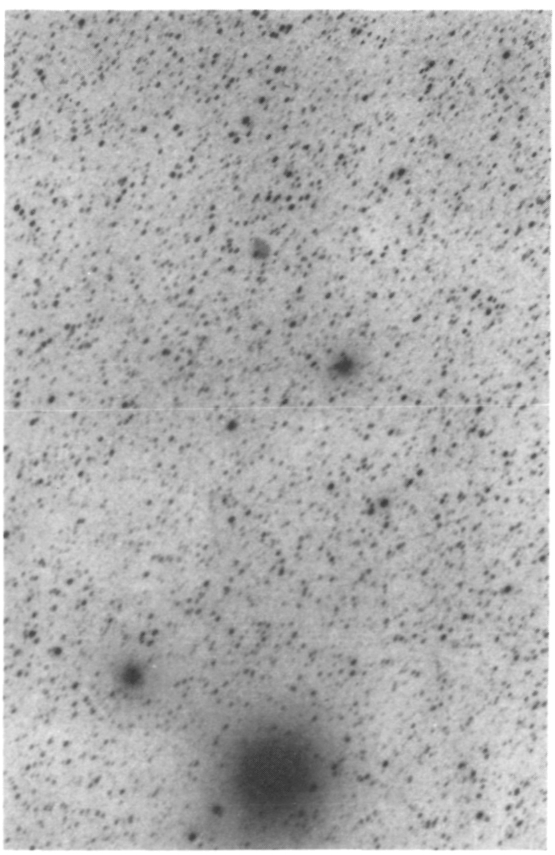
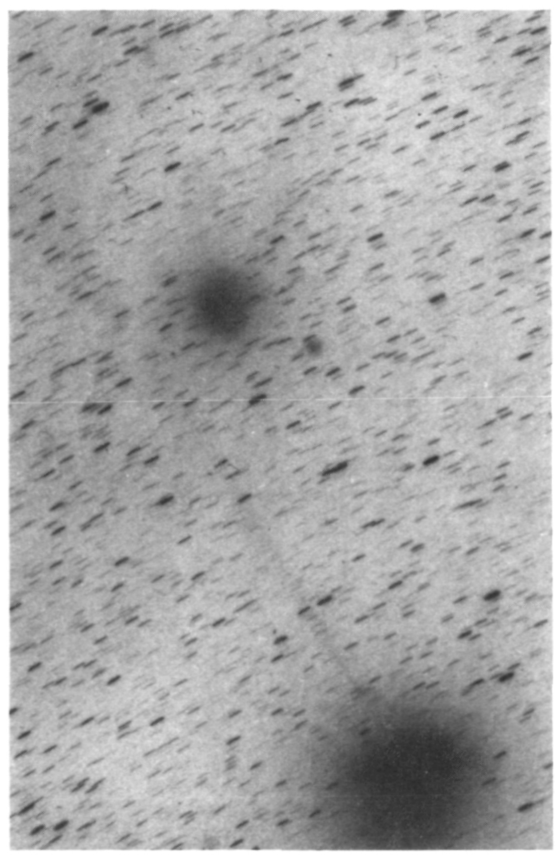
Photographic Observations of Comet IRAS-Araki-Alcock

Photographs taken of comet IRAS-Araki-Alcock at GSFC's Joint Observatory for Cometary Research (JOCR) showed, for one of the few times ever in the history of cometary study, the growth of a comet tail within 48 hours. Individual comets usually either have tails or they don't, and it is extremely rare to see one "grow from nowhere" so quickly. JOCR—the only observatory in the world expressly dedicated to comets, and located near Socorro, New Mexico—obtained the wide-angle images following the exciting discovery of the comet by the Infrared Astronomical Satellite (IRAS). On May 12, 1983, this comet passed closer to Earth (12 times the Earth-Moon distance) than any known comet in more than 200 years.

The sudden appearance of the tail is shown in the accompanying two photographs, which are reversed (i.e., negative) to show faint features in greater detail. The comet clearly has no tail on May 7 but just



Comet IRAS-Araki-Alcock on May 7, 1983. The comet is the large circular object near the bottom of the photograph.



The comet on May 9, 1983. Note the appearance since May 7 of a prominent tail.

as clearly *does* have one only two days later, on May 9. This interesting sequence of events suggests the arrival at the comet of either an enhanced amount of ultraviolet sunlight caused by an explosive solar flare, or a strong disturbance in the "solar wind" (a hot, tenuous ionized gas continuously flowing away from the Sun at supersonic speeds). Preliminary results suggest a solar-flare origin for the tail's sudden appearance, and even the specific flare is thought to be known. A more detailed study is underway which should tell a great deal about the interaction of ultraviolet sunlight with comets and about the formation of comet tails.

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The Outer Layers of "New" Comets

The prevailing hypothesis on comets is that they are kilometer-size icy objects that have remained at large distances from the Sun since the formation of the solar system, 4.5 billion years ago. Perturbations at rare intervals change some orbits so that they come within a few astronomical units of the Sun. A "new" comet is one doing this for the first time. During its long residence in the remote orbits, the Oort Cloud, a comet is exposed to the galactic cosmic ray flux. Calculations indicated that substantial chemical changes in the outer layers of a cometary nucleus were to be expected.

In order to obtain more definite information on chemical and other changes that may occur, experiments were carried out on irradiation of possible cometary ice mixtures. Combinations of water, ammonia, methane, carbon dioxide and nitrogen were exposed to a 1-MeV proton beam. The destruction of initial molecules and creation of new ones were detected by infrared spectroscopy. In addition to the molecular changes, other significant results were obtained that may explain the behavior of "new" comets. These were the formation of a nonvolatile residue at room temperature, pressure bursts and light flashes as an ice mixture was warmed from 15°K to nearly room temperature.

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Solar Physics

Variability of the Solar Energy Output

The purpose of the GSFC effort in this field is to measure and/or to model the variability of the total and spectral solar irradiance on time scales long enough to be of importance to terrestrial and planetary climate. An important element of this work is to achieve a physical understanding of the mechanisms that modulate solar irradiance, first to understand the observed changes, and later, to be able to predict them. This problem has theoretical, observational and experimental components.

Theoretical Studies

Extensive theoretical work carried out at the GSFC indicates that variations of the solar radius and luminosity are related in a complex fashion, generally depending on the physical mechanism which causes the variation, the depth within the Sun where it operates, and on time. Fortunately, however, all this complexity becomes simpler if we only consider those cases that have a significant probability of realism. We have found that if the perturbations causing the solar variability are so rare that any two sets of observations giving δR, the change in radius, and δL, the change in luminosity, were made after the perturbing event, then $W = \delta \ln R/\delta \ln L = 0.32 \pm 0.02$, regardless of any other characteristics of the perturbing event. If, on the other hand, the perturbing events are so frequent that for any set of two measurements one or more perturbing events occurred in between, then $W \sim 0.7 \pm 0.1$, provided that the perturbing event occurred below $R = 0.95 R_o$. For shallower perturbing events, W depends on too many parameters to be of any use at the present time. However, the most likely candidate for producing these solar changes is the variable magnetic field (the dynamo field) probably residing at the

base of the convection zone, near R = 0.75 R_o. Thus, according to the character of the perturbation, W = 0.3 or 0.7. Which relationship is the correct one must await experimental verification, and these results must be channeled back into the models to refine our understanding of the nature of the perturbations. Only a detailed understanding of the physical events involved will allow us to determine whether these events are predictable.

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Experimental Studies

The methods of obtaining the variations of the solar luminosity with the required accuracy already exist, such as, for example, active cavity radiometers (e.g., the ACRIM experiment on SMM) which measure the total solar irradiance, S. Because the total irradiance is affected by active regions on the Sun, modeling of the active regions modulation must be improved not to degrade the accuracy of the S measurements. By means of this modeling, δS can be converted into δL. We must be able to measure δR with comparable accuracy. An instrument to measure δR with a long-term accuracy of 10^{-6} R_o is being developed at the GSFC. The instrument, called the Solar Disk Sextant (SDS) incorporates a beam-splitting wedge which decreases the instrumental stability requirement to achieve a given accuracy by nearly two orders of magnitude, and also allows scale calibration in solar observations not available in previous experiments. A version of the SDS for balloon or Shuttle flight in late 1984 is currently being assembled, and designs for a freeflyer are about to begin for flight at the end of the decade.

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Observational Studies

We are studying the past behavior of the solar radius by means of timing observations of past total solar eclipses (for over two centuries) so that, upon obtaining a definitive value of W, we can find the past variations of the solar luminosity. We will also study δR on a long-term basis in the future as an alternate means of monitoring δL (i.e., in addition to the direct observation), and also to determine such solar properties as oblateness and spectrum of solar pulsations. The results of these studies will be fed back into our modeling to refine our understanding of the solar interior in order to achieve predictability of the solar changes.

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Solar Ultraviolet Flux Measurements

Continued concern about the stability of the Earth's ozone layer has increased scientific interest in determining the variability of the Sun as an ultraviolet light source. The wavelength region of interest is 120 to 400 nm where the energy of the solar protons is sufficient to dissociate molecules involved in either the photochemical production or destruction of ozone. To this end, periodic measurements are made of the Sun's intensity using sounding rockets, high-altitude balloons, and instruments such as the Solar Backscattered Ultraviolet Experiment on the Nimbus-7 satellite.

Previous measurements by NASA/Goddard Space Flight Center (GSFC) scientists are believed to be accurate to ±10 percent. Examination of solar flux data obtained from three rocket flights bracketing solar maximum (November 16, 1978, May 22, 1980 and October 16, 1980) indicate that only small changes occurred in the solar irradiance between 160 nm and 200 nm. The spectra from the 1978 and 1980 flights are virtually identical while the irradiance measured in 1981 lies ~ 20 percent lower. This 20-percent difference lies outside the error bars

of the measurement but since the number of measurements is limited, it is possible that the last flight contains a spurious error. To improve the reliability of the results, the calibration procedures at the GSFC have been improved by designing a number of test fixtures. This has improved the absolute accuracy to $\sim \pm 5$ percent and the precision to $\sim \pm 2$ percent. Rocket measurements to be repeated at 1-year intervals will determine the solar variability in this wavelength region.

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Solar Maximum Mission Ozone

The ultraviolet spectrometer polarimeter on the Solar Maximum Mission satellite has been employed to measure the distribution of ozone in the terrestrial atmosphere by means of the solar occultation technique. The altitude region between 50 and 70 km, which is termed the mesosphere, has been studied during the recent 1980 solar sunspot cycle. X-rays and middle ultraviolet radiation constitute one of the most sensitive parts of the solar spectrum to solar activity. These radiations are absorbed in the mesosphere so that the distribution of mesospheric trace gases will also be influenced. Gases such as ozone and nitric oxide attenuate other radiation, which affects directly the stratosphere and lower atmosphere. Analysis of the ozone data in the equatorial region indicates that the profiles can be explained by a photochemical theory which includes only the influence of hydrogen compounds on the ozone distribution. This simplified system aids in the study of stratospheric ozone, where theory includes not only hydrogen but also nitrogen and chlorine compounds. Hydrogen compounds arise from the breakdown of water, which diffuses into the mesosphere from lower altitudes. The water concentration deduced from the ozone distribution is a factor of 2 to 3 less than the commonly accepted value of 6 parts per million implying a slower rate of diffusion from lower altitudes.

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Observations and Computer Modeling of Solar Flares

Solar flares, the bright, hot explosions that occur on and above the solar surface have interested astronomers for over a century. Research has focused on how such a large amount of energy is released so rapidly and how it is transported through the solar system.

Combining a computer modeling program (including most of the energy transport and hydrodynamic physical processes expected to occur in solar flares) with observations from several telescopes on the Solar Maximum Mission (SMM) satellite, Goddard astronomers have been able to limit the possible mechanisms for energy transport in flares. The results are most supportive of a flare mechanism that includes acceleration of high energy electrons in a magnetic loop. These electrons then collide with the ambient denser gas yielding hard X-rays and heat. The heating causes enhanced radiation in emission lines from plasma in the temperature range from 10,000°K to tens of millions of degrees and causes material to be ejected from the solar surface. One such flare and its ejection, as observed by the Ultraviolet Spectrometer Polarimeter in lines at 250,000°K (a, c, e) and 10,000,000 (b, d, f) can be seen in the photographs.

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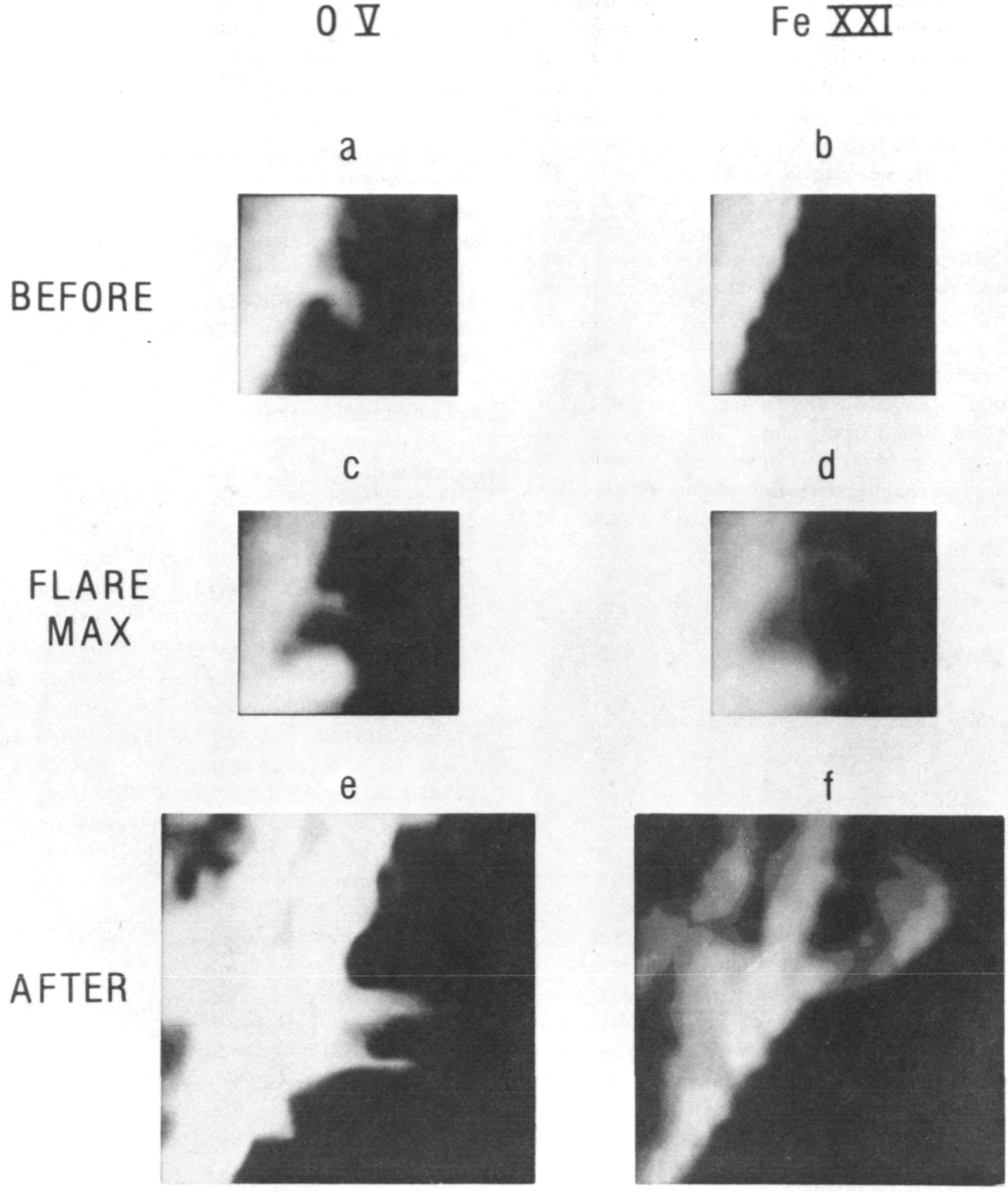
Nuclear Reactions in Solar Flares

The first detailed calculations of the expected rate of nuclear reactions in solar flares were carried out in 1967 by Lingenfelter and Ramaty who predicted that the interaction of flare-accelerated energetic particles with the solar atmosphere should



Solar flare as observed by the Ultraviolet Spectrometer Polarimeter.

produce detectable fluxes of gamma-ray lines and high-energy neutrons. Following the first observations of gamma-ray lines from flares with a spectrometer built by E. L. Chupp and coworkers and flown on OSO-7 in 1972, a wealth of gamma-ray line and neutron data has been accumulated, principally by observations with the spectrometer currently in orbit on the Solar Maximum Mission satellite. The ongoing theoretical analyses of these observations are providing new insights into a variety of problems in solar physics. In particular, they have given information on the energy spectrum and directionality of the accelerated particle in flares, on the timing of their acceleration, on the location of both the acceleration and interaction sites, and on the composition of the site of the nuclear interactions, most likely the solar chromosphere. The success of this program depends on detailed research in a variety of physical disciplines, including plasma physics (for the study of the acceleration mechanisms) and nuclear and atomic physics.

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A Pioneer Venus Solar EUV Monitor

Solar extreme ultraviolet (EUV) radiation causes the emission of photoelectrons from metallic surfaces in space. Thus satellite-borne Langmuir probes, while operating above the ionosphere, provide a means of monitoring the solar EUV flux at wavelengths which exceed the work function of the collector surfaces that are exposed to the Sun. Such collectors produce emission at wavelengths less than about 1400 Å. Satellite spectrophotometer measurements from Atmosphere Explorer-C (AE-C) have shown that about half of the photoemission is due to the hydrogen Lyman α and Lyman β lines, and the rest is produced by the shorter wavelength lines which are the primary source of ion and photoelectron production in the ionosphere. Both of these components exhibit similar flux variations with solar activity.

The Pioneer Venus Orbiter Electron Temperature Probe (OETP) provided our first opportunity to examine the correlation between the solar EUV flux and the photoemission currents. The ideal time to investigate this question came in September and October of 1980 when Venus and Earth viewed nearly the same face of the Sun for two solar rotations. Thus the AE-C EUV measurements from Earth orbit and the PV-OETP photoelectron measurements in Venus orbit could be compared directly, without correction for solar rotation. The figure compares the daily measurements of Ly α and Ly β at Earth with the Venus OETP EUV index and with the ground-based measurements of the $F_{10.7}$ cm index of solar activity. Although all three exhibit a similar 27-day solar rotational period, the OETP index appears to better represent the overall shape of the EUV than does the 10.7-cm index.

We expect that the Venus EUV index will be used extensively in the future, not only as a more accurate representation of the actual EUV radiation, but also as a means of tracking specific active regions on the Sun after they have rotated out of view from Earth. Work is proceeding to improve the resolution of the photoelectron analysis (which will decrease the scatter in the data), and to identify and calibrate any long-term changes in photoelectric yield and thus improve the absolute accuracy of the OETP EUV index.

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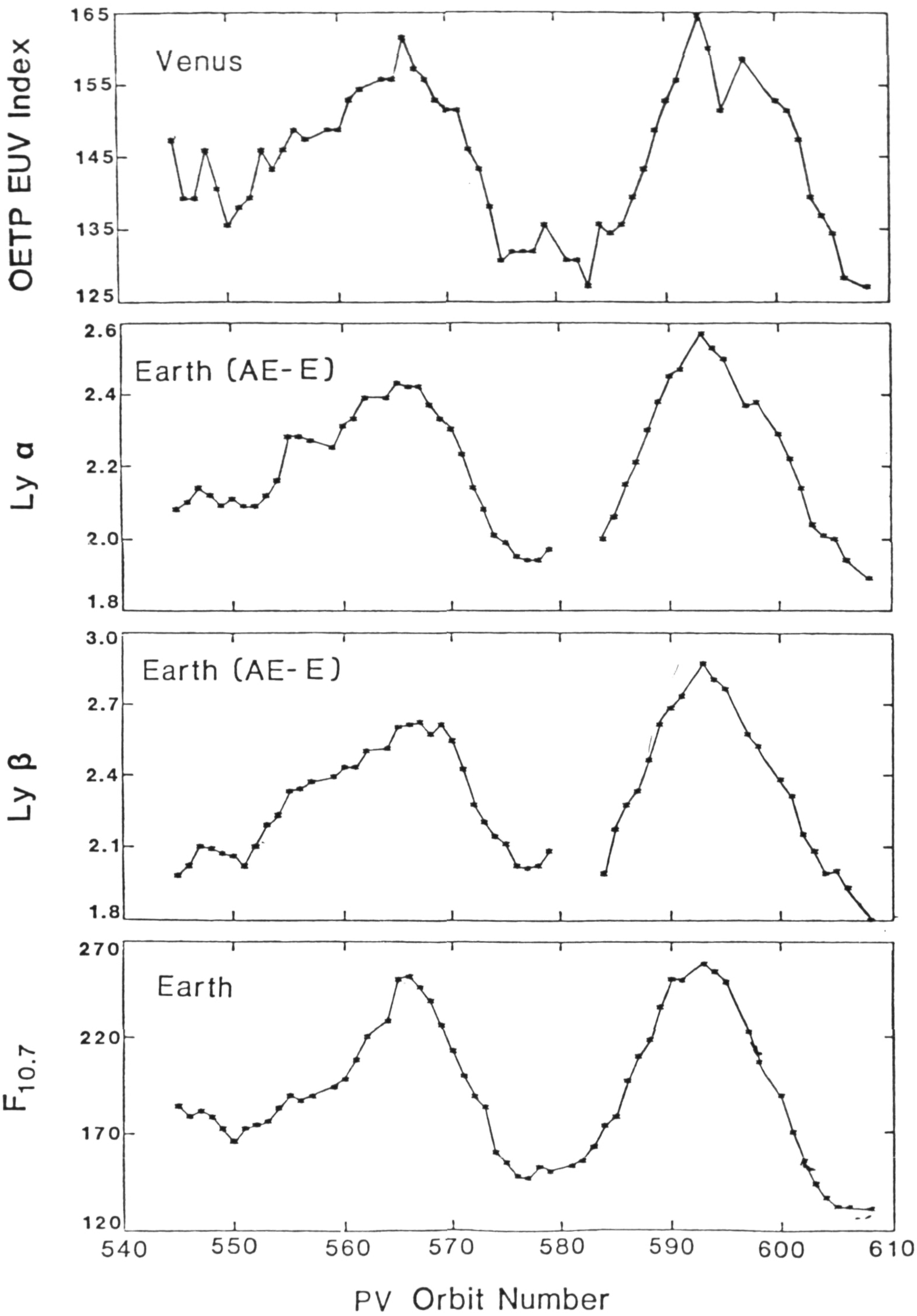

Comparison of the daily measurements of Ly α and Ly β at Earth with the Venus Orbiter Electron Temperature Probe EUV index and with the ground-based measurements of the $F_{10.7}$ cm index of solar activity.

SPACE PLASMA PHYSICS

Interplanetary Medium

Remote Measurement of Solar Wind Speed

A new technique has been developed to measure the velocity of portions of the solar wind during its flow outward from the Sun. This analysis utilizes spacecraft (ISEE-3) observations of radio emission generated in specific regions of the solar wind which are associated with active regions. The radio emission consists of many thousands of type III radio bursts per day constituting solar radio interplanetary storms which were first discovered by the GSFC using the spacecraft RAE-1, and later studied extensively using ISEE-3. These storms, occurring several times per solar rotation near solar maximum, have been shown to be the low-frequency extension of phenomena from solar active regions into interplanetary space.

By tracking the source of these radio waves over periods of days, we are able to measure the motion of the associated emission region, and thereby determine the velocity of the solar wind. Our first results also show a slight acceleration of the solar wind from 50 solar radii out to 150 solar radii, consistent with theoretical models of the solar wind.

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Turbulence in the Solar Wind

To describe a fluid system as turbulent is to say that the dynamical fluid variables exhibit complex and essentially nonreproducible behavior as a function of time. From a theoretical point of view this usually arises from nonlinearities in the fluid equations which strongly couple a large number of degrees of freedom. By all appearances the solar wind plasma flow and magnetic field are such a turbulent system. The availability of a vast data base of magnetic field and plasma properties along spacecraft trajectories now provides the opportunity to evaluate existing turbulence theories and may provide guides for developing new approaches. Using magnetic field data from ISEE-3 and Voyager spacecraft, we have found that the solar wind magnetic fields approximate a random stationary process as expected from the ergodic theorem (generalized to include the effects of the low-frequency coherent input of phenomena driven at the solar rotation period). This finding justifies the validity of constructing correlation functions and power spectra, quantities essential for describing turbulent systems. The long-standing observation that Alfvenic fluctuations in the solar wind are almost always seen to propagate outward from the Sun has usually been interpreted as a remnant of coronal processes in which only the outward directed "waves" can enter the super-Alfvenic flow of the interplanetary medium. However, an alternative interpretation has arisen in which it is the high-speed streams which drive the turbulent cascade of magnetic energy. Computer simulations and arguments based on the equations of magnetohydrodynamics (MHD) demonstrate that at the early stages of this cascade, Alfvenic fluctuations will propagate outward as observed. At larger heliocentric distances, a mixture of inward and outward propagation can be expected. An example of such a mixture of propagation directions had previously been found in the Voyager data at 5 AU.

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Low-frequency Waves in the Solar Wind

Highly coherent, strongly compressional, low-frequency magnetohydrodynamic waves (frequencies near 10^{-4} Hz) were detected by Voyager-2 in the solar wind following the Saturn encounter. The periods of the waves were found to range from ~ 1.5

hrs to > 2 hrs. The waves persisted for intervals ranging in length from < 1 day to ~ 13 days and were observed at distances from Saturn ranging from ~ 150 R_s to ~ 2800 R_s. R_s = Saturn radius = 60,000 km. The markedly sinusoidal nature of these waves had not previously been observed at such low frequencies.

Analysis has revealed that the waves were > 90 percent polarized near the peak frequencies, were highly elliptical, and propagated at large angles (60° to 70°) to the magnetic field. The waves are thought to be stimulated by energetic particles streaming from the direction of Saturn. Clear association with enhancements in the count rates of 28 to 200 keV ions were found for the 3 occurrence intervals nearest Saturn.

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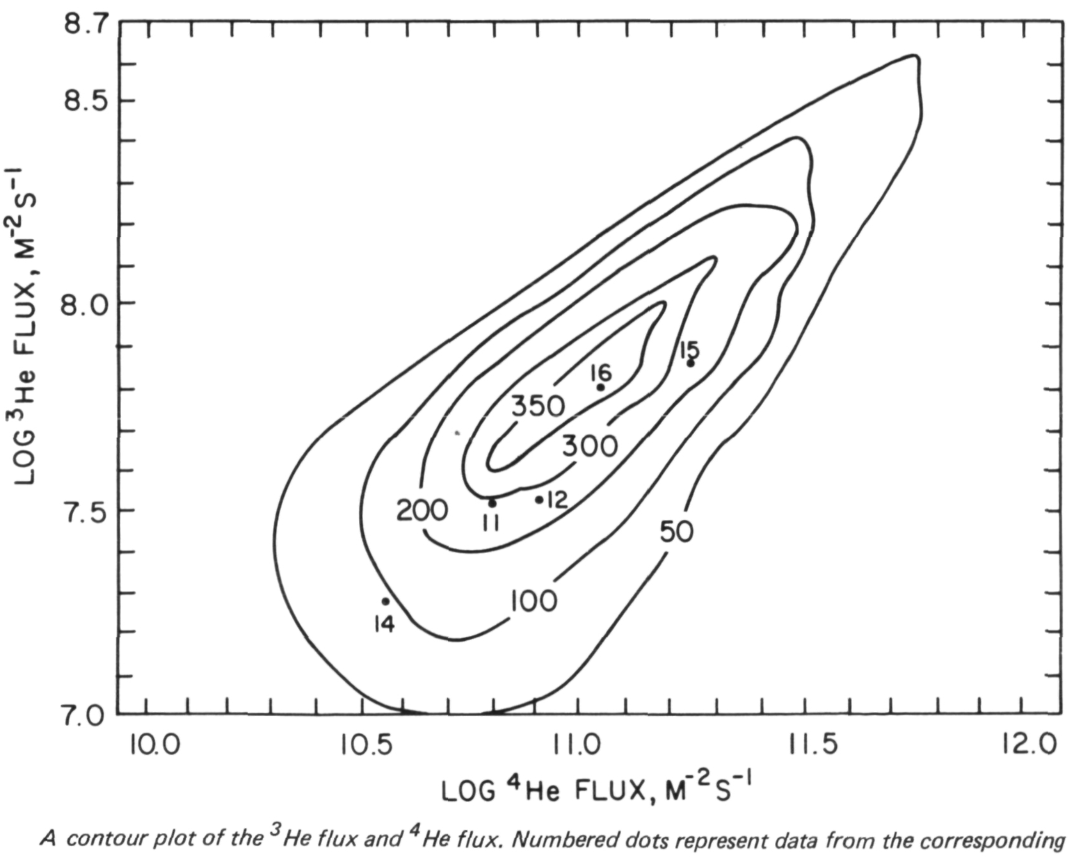
^{3}He in the Solar Wind

Helium, the second most abundant element, occurs as two isotopes, the abundant one with mass 4, and a much less abundant one with mass 3. The total flux of Helium varies greatly in the solar wind and the ratio R of the fluxes of the isotopes also varies. The abundance of ^{3}He is interesting both because it has increased in the past 4.5×10^9 y. due to production in the Sun and also because ^{3}He is identical to the heavier isotope except for its mass. Thus variations in the flux ratio has astrophysical interest and can shed light on solar wind acceleration mechanisms.

During the Apollo flights to the Moon, astronauts held up aluminum foils to receive the solar wind and subsequently brought them back to Earth, where heating released trapped noble gases for study. The spacecraft ISEE-3 carries a mass spectrometer which can measure ^{3}He directly. After 4 years of operation, the data from this instrument has been analyzed and can be compared to the results of the foil measurements on the Apollo flights. The attached figure is a



A contour plot of the ^{3}He flux and ^{4}He flux. Numbered dots represent data from the corresponding Apollo flight.

contour plot with the logorithm of the ^3He flux (in particles per sec per meter^2) plotted vertically and the logarithm of the ^4He flux plotted horizontally. Contours join places where a given combination of isotopic fluxes was observed a given number of times, and the numbered dots represent data from the corresponding Apollo flight. Thus the combination of fluxes observed on Apollo-11 falls on the 300 contour. We see at once that the Apollo foil experiments form a fully representative set of observations, since most of them fall close to our maximal contours. The average value of ^4He flux/^3He flux (= 2110 ± 150) also agrees well with the average Apollo result (= 2350 ± 120).

The fluctuations, represented by the length and breadth of the contours, are being studied to determine what information they can give about how ions are accelerated into the solar wind. Already they have confirmed the idea that rarer ions are accelerated as a result of Coulomb drag between them and the dominant proton stream. This can be done because the drag per unit mass is roughly proportional to Z^2/A, which is different for the two species.

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Evolution of a Large Interplanetary Shock

A soft X-ray event began early on September 4, 1982 and lasted for more than 24 hours. The associated double-ribbon event persisted during September 4-6 in the Kitt Peak He I 10830 Å images. A "head-on" coronal mass ejection was observed with the NRL coronagraph during 0324-0459 UT on September 4. The joint Meudon-GSFC radio mapping experiment on ISEE-3 traced the interplanetary shock at an average speed of 930 km/sec from 8 solar radii to ISEE-3 where the *in situ* shock was recorded late on September 5. Several minutes later the shock reached Earth and signaled the start of one of the largest geomagnetic storms of the present sunspot cycle.

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Large Amplitude Magnetohydrodynamic (MHD) Waves Near Planetary Bow Shocks

A distinct class of solar wind magnetic fluctuations localized to planetary foreshocks is often observed when the magnetic field is "connected" to that bowshock. Most observations of this phenomenon have been made in the Earth's foreshock, but a very interesting and complex series of observations were made by Voyager 2 shortly before entry into the Jovian magnetosphere. The events spanned 6 days and coincided with energetic particle events. The wave amplitudes reached that of the average field and the wave periods were near 500 seconds. The waves were shown to be propagating in the fast MHD mode. By determining the spectra of the three rugged invariants of energy, magnetic helicity, and cross helicity and using standard plasma instability theory, evidence was found that the medium upstream of the bow shock was being stirred by solar wind protons that had been reflected off the shock and were propagating back upstream. At times the magnetic spectrum showed the classic (Kolmogoroff) power-law slope above a few MHz with a harder spectrum at lower frequencies, suggestive of an inverse cascade of magnetic energy to larger spatial scales as expected of MHD turbulence. Similar studies using ISEE and/or Voyager data have been performed in the vicinity of interplanetary shocks, the Saturn bow shock, and the terrestrial bow shock.

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ISEE-1 Electron Velocity Distributions in the Earth's Electron Foreshock

The electron foreshock is a region in the solar wind flow, upstream of the Earth's bow shock. It is filled with energetic electrons which are accelerated in the bow shock and then propagate upstream, away from the shock, into interplanetary space. It has been known since the early 1970's that these energetic electrons excite intense bursts of electrostatic radio emissions as they pass through the foreshock region. The generally accepted theoretical explanation for these emissions is based on plasma phenomena which occur following the injection of a type of beam of electrons into the interplanetary plasma. However, until recently the existence of this beam has not been confirmed experimentally.

The Goddard Electron Spectrometer experiment, in orbit on the ISEE-1 spacecraft since the fall of 1977, was designed to have high time and electron velocity resolution. It has been found that the resolution of this instrument is sufficient to allow a detailed study of the electron distribution within the electron foreshock. The presumed energetic electron beam has been confirmed using the Electron Spectrometer data; the beam has been found in a thin layer of space at the upstream boundary of the foreshock. These high-resolution measurements of the electron distribution within this layer generally support the earlier theoretical explanations for the electrostatic radio emissions in the foreshock and also point the way for a deeper study of the important beam injection problem.

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Jovian Magnetotail Current Sheet

During the outbound leg of its passage through the Jovian Magnetosphere in July 1979, the Voyager-2 spacecraft observed >50 traversals of the magnetotail current sheet at distances between 30 and 130 R_J. Analysis of these observations has shown that the tail sheet of Jupiter tends to lie approximately parallel to the ecliptic plane and to oscillate about the tail axis with the 10-hour planetary rotation period.

A detailed study of the sheet's fine structure as observed by Voyager-2 and also to a limited extent by Voyager-1 shows that it varied in structural complexity with time and also changed character with distance from the planet. The various magnetic signatures of the sheet traversals have been found to be similar to those observed by spacecraft at the current sheet in the Earth's magnetotail at different times. The more complex forms observed suggest a loop geometry and fine structure consistent with the tearing mode instability and the occurrence of magnetic reconnection in Jupiter's tail.

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Type III Radio Storm Exciters

Long-lasting storms of type III radio bursts (IP storms) are observed by ISEE-3 in the interplanetary medium out to 0.5 to 0.8 AU. They provide indirect evidence of the existence of long-lasting, corotating streams of suprathermal electrons which are accelerated near 1.5 solar radius heliocentric. For some storms, the shape of the trajectory of the inferred electron streams can be determined from the radio observations. An increase in the energetic particle flux is observed at 1 AU by the energetic particle experiment (University of California) on ISEE-3 at times when the corotating stream trajectories are predicted to cross the spacecraft. These electrons present a narrow pitch angle distribution aligned with the local magnetic field, which demonstrates that the particles are coming from the Sun.

The average half-flux angular extent of the electron streams is 25°, while the average radio source size is 50° (as seen from the Sun). This difference is interpreted as evidence for scattering of the radio waves, close to the source region. The absence of type III storm radio emission at distances larger than 0.5 to 0.8 AU, even though the energetic particles are observed, is interpreted as the result of the superposition of many individual beams of increased radial extent, resulting in the smoothing of the bump-on tail of the velocity distribution function at large distances from the Sun. It appears that the IP storms provide a unique means to remotely track and analyze corotating streams of energetic electrons which are directly associated with the solar active regions.

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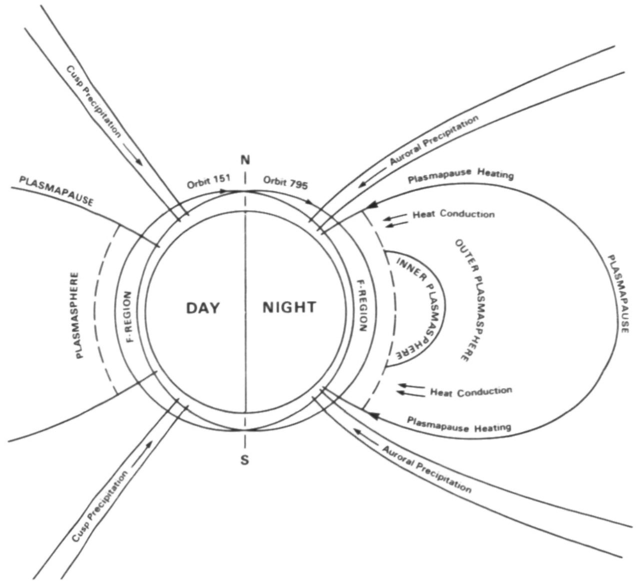
Magnetosphere

Coupling of Magnetospheric Energy into the Earth's Ionosphere

The Dynamics Explorer-1 and -2 satellite data are confirming and beginning to make more quantitative the long-held view that the magnetosphere supplies the dominant source of energy globally for heating the ionosphere. The global distribution of this magnetospheric heat input is particularly evident as regions of enhanced electron temperature at middle and high latitudes. The figure illustrates this, where areas of heat flow are indicated by the arrows. The path of two specific orbits illustrates how DE-2 traverses these regions. Three major areas of ionospheric heating are evident globally; heating by conduction from the outer plasmasphere, heating at the plasmapause, and heating in the auroral oval and at the dayside cusp.

Beginning at low latitudes in the figure, the plasmasphere stores the photoelectron energy it receives from the ionosphere during the day and leaks it slowly back into the ionosphere at night. The heat



The path of two orbits illustrating the global distribution of the magnetospheric heat input to the ionosphere.

content of the inner plasmasphere is insufficient to keep the ionosphere from cooling completely to the neutral gas temperature within a few hours after sunset, but the outer plasmasphere has stored enough energy to keep the ionosphere warm all night.

Moving poleward in the figure, an additional enhancement of electron temperature occurs at middle latitudes where the plasmapause magnetic field lines intersect the ionospheric F-region. During the recovery phase which follows magnetic substorms, the electron temperature in this region often rises high enough to excite neutral atomic oxygen 6300 Å emission to produce an airglow phenomenon known as a red arc. These features stretch from east to west across the night sky over the northern United States. The source of heat for this phenomenon is believed to lie in the interaction of trapped magnetospheric plasma with the low-energy plasma of the plasmasphere, possibly at specific locations along the plasmapause where the magnetic field strength and plasma conditions are conductive to the growth of plasma instabilities. The simultaneous measurements of DE-1 and -2 instruments at various points along the plasmapause surface are helping to identify these regions where the magnetosphere exchanges energy with the ionosphere.

At still higher latitudes, the precipitation of auroral electrons provides an even stronger heating of the ionosphere, particularly at the cusp on the dayside where the electron energies are low enough that they deposit their heat in the F-region where the DE-2 measurements are made. Peaks of electron temperature exceeding 10,000°K are often observed in the cusp, nearly 10 times the neutral gas and ion temperatures.

Through the study of simultaneously obtained sets of DE-1 data in the magnetosphere and DE-2 data in the ionosphere, DE investigators are attempting to uncover the processes that generate the high-energy magnetospheric plasma and that couples that energy into the ionosphere and eventually into the upper atmosphere itself.

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Field-Aligned Currents in the Magnetosphere — Ionospheric System

Huge field-aligned currents reaching toward 800 microamps/m^2 have been observed in the ionosphere by Dynamics Explorer-2. These very narrow current regions have been identified because of the high temporal resolution measurement capabilities of the magnetometer. Previous work had shown currents only in the tenths to tens of microamp/m^2 range, which had created problems for theorists seeking confirmation of currents with sufficient strength to produce current-driven instabilities. Now DE frequently finds currents exceeding 100 microamps/m^2 sufficient to cause these plasma instabilities.

Analyses of both the field-aligned currents, measured through their magnetic signatures, and measurements of electron and ion distributions have produced the first global description of the carriers of field-aligned currents. Upward currents at all local times are primarily carried by precipitating energetic electrons (i.e., greater than a few eV). In the premidnight, active auroral region, these electrons are usually associated with the aurora. Since ions have not been observed to carry significant currents at any local time, the downward currents must be carried by upward-moving thermal electrons, a current which cannot be measured directly by any available technique.

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Magnetic Reconnection at the Earth's Magnetopause

Direct evidence of magnetic merging or "reconnection" at the Earth's magnetopause has been discovered using the electric field measurements from ISEE-1. When the interplanetary magnetic field is southward, the outward moving interplanetary magnetic field lines are thought to connect themselves to the Earth's magnetic field lines at the magnetopause, and drag them into the magnetotail. This reconnection process is thought to be the driving mechanism for many magnetospheric phenomena. At such reconnecting magnetopauses (rotational magnetopause discontinuities), a special coordinate system moving with a velocity $\vec{V}_o$ has been found in which the electric field vanishes on both sides and within the magnetopause in accordance with magnetohydrodynamic theory. Combining $\vec{V}_o$, the magnetic field, and the mass density allows values of the electric field and plasma velocity in the satellite coordinate system to be calculated which are in good agreement with the *in situ* measurements. The length of time over which a particular $\vec{V}_o$ fits the data is an indicator of the stability of the reconnection process. Time periods of up to 20 minutes indicate that, at least in some cases, reconnection is a steady-state process. Time variable cases are also observed.

Two magnetohydrodynamic solutions exist. In the first, plasma is accelerated at the magnetopause. Convective electric fields corresponding to the accelerated plasma velocity component perpendicular to the magnetic field have been observed with magnitudes of up to 22 mV/m in the magnetopause boundary layer. In the other solution, plasma is decelerated

on entry into the magnetosphere and $\vec{E} \cdot \vec{J}$ is negative. Energy is transferred locally from kinetic energy to electromagnetic energy. The accompanying figure shows a comparison of the measured electron velocity with that calculated from $\vec{V}_o$ for this second type of reconnective magnetopause geometries. It is unknown how common this second type solution is, as previous searches for reconnection events have concentrated on looking for plasma accelerations.

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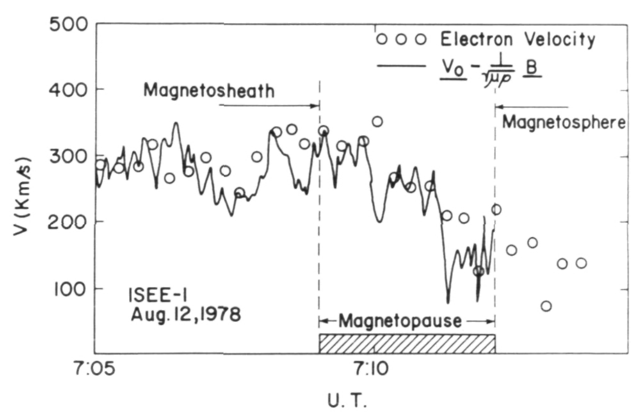

A comparison of the measured electron velocity.

Magnetospheric Electrons and the Diffuse Aurora

Electrons in the plasma sheet of the Earth's magnetotail spiral rapidly back and forth along magnetic field lines (in seconds) while the entire plasma convects slowly toward and around the Earth (in many tens of minutes). These trapped electrons interact with very low frequency magnetospheric waves, and some of their trajectories are perturbed so that they precipitate into the atmosphere and produce the diffuse aurora. Previous theories have assumed that this loss would occur so rapidly that the electrons would be lost before they could convect inside a radial distance of 7 to 9 Earth radii (R_e), but the ISEE-1 electron spectrometer measurements indicate that these electrons often approach to within 4 to 5 R_e of the Earth in the dawn hemisphere and are frequently found adjacent to the very low energy electrons of the plasmasphere. The new ISEE satellite observations indicate that the wave particle interactions are not as strong as has often been supposed; strong diffusion does not usually occur. Instead, the process of removing electrons from the magnetosphere and depositing them in the polar atmosphere to cause the diffuse, quiet-time aurora proceeds more slowly than originally was thought.

These high resolution ISEE measurements also indicate that field lines near the inner edge of the plasma sheet contain an excess of lower energy electrons relative to higher energy electrons, and an excess of electrons mirroring closer to the Earth compared to those mirroring nearer the equatorial plane. These characteristics can apparently be explained by the theory for the motion of particles in magnetospheric electric and magnetic fields without considering diffusion processes. The anisotropic distributions may be unstable to the creation of waves which precipitate the electrons.

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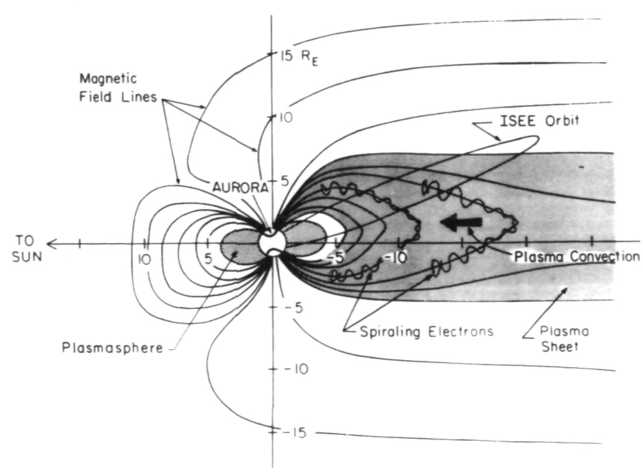

ISEE satellite observations indicating wave particle interactions.

Plasma Electrons in Saturn's Magnetosphere

During the Voyager encounters with Saturn, low-energy (10 eV to 5950 eV) plasma electron observations were made. The analysis of this data set, which self-consistently included the effects of the spacecraft potential, has revealed the presence of three distinct plasma regimes as shown in the figure: the hot outer magnetosphere, the extended plasma sheet, and the inner plasma torus. A large-scale radial gradient in the electron temperature T_e was observed, with T_e being as small as 1 eV near the inner edge of the inner plasma torus ($L \sim 3$) and as high as 1 keV in the hot outer magnetosphere ($L > 15$). Localized reductions in the electron temperature centered on the L shells of Dione, Tethys and possibly Rhea were observed. Around noon local time, brief enhancements of cold plasma have been observed within the hot outer magnetosphere; these density enhancements have been interpreted as being detached segments of the extended plasma sheet which have broken off because of centrifugal forces. Other density enhancements have been identified as Titan plumes. The electrons, like the ions, are composed of cold (thermal) and hot (suprathermal) components. The data reveal a large-scale energy-dependent depletion of the suprathermal electrons within the inner magnetosphere ($L < 10$), which we think is due to interactions with dust and/or precipitation by plasma waves.

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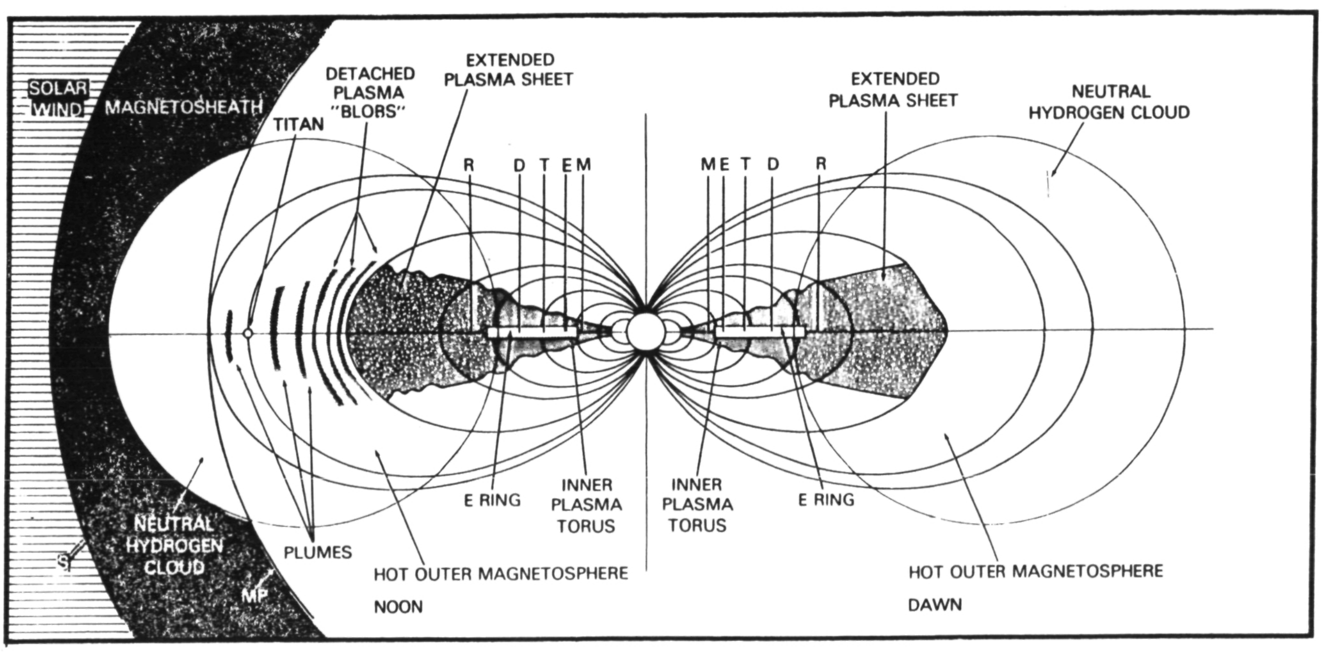

Plasma electron observations of Voyager's encounter with Saturn.

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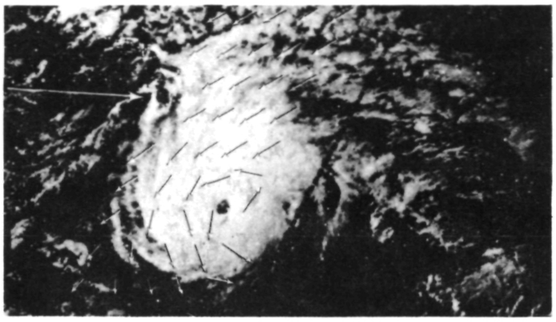
EARTH SCIENCE AND APPLICATIONS

GSFC's program in Earth science and applications has in recent years emphasized the basic science involved in the study of Earth's atmosphere, oceans, and land masses. Satellite data have been particularly useful in studies of the Earth's climate, the dynamics of its crust, and in the monitoring of its land and water resources. GSFC scientists continue to pursue a wide variety of research studies in these areas.



LOWER ATMOSPHERE

Weather and Climate

Weather and Climate Parameters from Multispectral Soundings

Six months of 1979 Tiros-N HIRS2/MSU data have been processed using the GLAS physical inversion method, by which important weather and climate parameters are extracted from the multispectral observations. In addition to atmospheric temperature profiles, global monthly mean fields of sea or land surface temperatures, surface emissivity at 50.3 GHz, and effective fractional cloud cover, cloud top temperature, and cloud top pressure have been prepared.

The global fields of surface temperature and surface emissivity represent the first such fields ever produced. Sea surface temperatures show excellent agreement with ground truth. The HIRS2/MSU derived fields of sea surface temperature are currently being intercompared with those derived from AVHRR and SMMR in a series of NASA-sponsored sea surface temperature intercomparison workshops. The ground temperatures are difficult to verify, but their diurnal variations show excellent agreement with a vegetation index as determined from analysis of AVHRR visible data. The surface emissivity, which is sensitive to sea ice extent and snow cover over land, has been shown to give excellent agreement with ice fields obtained from SMMR and snow cover from AVHRR imagery. In addition, the retrieved cloud parameters are consistent with outgoing long-wave radiation derived from AVHRR and also with monthly mean fields of vertical velocities and rainfall derived from the GLAS GCM. Detailed verification studies of all fields are underway.

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Dynamics of Teleconnections in Long-Range Forecasting and Climate

The dynamics of equatorially forced climate teleconnections on the sphere is studied using quasigeostrophic wave theory and numerical models. Using

the concept of a refractive index for meridional propagation of energy, it is demonstrated that for zonal mean flow with no horizontal shear, steady-state atmospheric teleconnections are composed of radiating Rossby modes, which are forced in weak westerly zonal mean flow and of evanescent modes in easterly zonal mean flow. For horizontally sheared zonal mean flow, westerly shear will lead to initial transient growth of wave packets with northwest-southeast tilt. These wave packets will move initially northward from the source region near the Equator and subsequently become damped after turning southward at various critical latitudes. In contrast, easterly shear will always cause monotonic decay of all north-bound wave packets from the tropics. The results imply that in the case of a barotropically stable mean flow, the kinematic shearing effect will focus or defocus wave energy from tropics to mid-latitudes depending on whether the ambient horizontal shear is westerly or easterly. This mechanism also explains why tropical wave energy is naturally drawn towards the climatological winter jet streams.

Experiments with a nonlinear baratropic spectral model with equatorial forcing shows that wave energy can still propagate away from regions of initially weak tropical easterly mean flow by the shear-induced growth mechanism which modifies the zero-wind line downstream of the source. The interaction of the winter subtropical westerly jet and the wave disturbance generated by a diabatic heat source over the Equator produces a quasistationary wave pattern reminiscent of the Pacific-North America Pattern. The gross features of the tropical and extratropical steady-state response in the radiating mode are in qualitative agreement with that predicted from linear theory.

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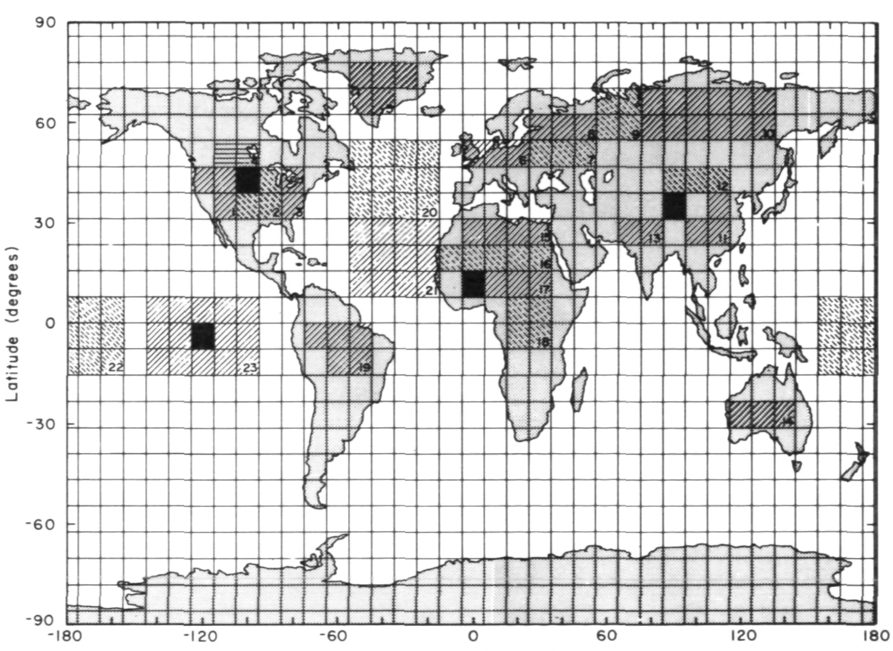
Long Range Climate Studies

Long range climate, principally on time scales of 10 to 100 years, is further studied. As a primary tool for these studies, an efficient three-dimensional global climate model has been developed over the past several years. This model, documented in the April 1983 issue of *Monthly Weather Review*, uses a coarse horizontal resolution as illustrated in the figure. This resolution, sufficient to define global climate patterns but not local weather events, permits simulation of climate change over decade-long periods.



Grid spacing for 8° X 10° global climate model. Shaded areas are a particular choice of the regions for which extensive diagnostics studies are performed.

Applications of this model are now being made to studies of the climate effect of increasing carbon dioxide and trace gases, and variations of solar irradiance and volcanic aerosols. Special effort is being made to determine the role of clouds, the dominant radiative constituent of the atmosphere, in climate sensitivity. The objective of these studies is a simulation capability which will permit analysis of both natural climate fluctuations and man's impact on long-range climate trends. Successful realization will depend upon both improved modeling ability and better global observations, especially for cloud distributions and ocean circulation.

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Global Cloud Climatology

Analyses of satellite data to infer global cloud property distributions are being performed. This research has contributed to planning for the International Satellite Cloud Climatology Project (ISCCP) and to preparations for GISS to serve as the ISCCP Global Processing Center (GPC). The GPC is responsible for analysis of the global satellite radiance data to produce an experimental global cloud climatology. Research has focused on development of cloud analysis techniques and intercomparison of methods to define the state-of-the-art technique to be used for ISCCP. As part of our research programs, a preliminary seasonal cloud climatology was obtained from polar orbiter data during 1983. Completion of the cloud algorithm intercomparison in 1983 allowed definition of the ISCCP algorithm. The figure shows that the cloud cover obtained by different methods agrees to within 15 percent averaged over all results; however, closer examination of these results revealed shortcomings of each method for particular types of clouds and weather systems. A hybrid bispectral threshold method seems to produce the best results. ISCCP data collection began July 1, 1983.

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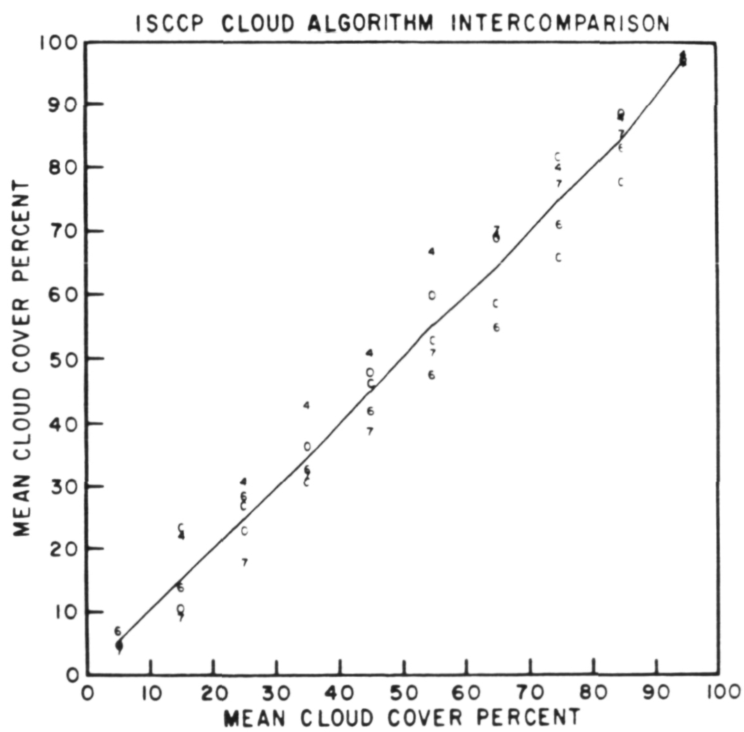

Average cloud cover fraction obtained by five different algorithms applied to the same visible and infrared radiance data. Each symbol represents the cloud fraction obtained by a single algorithm, averaged over five days and three geographic regions (eastern U.S.A.-Canada, northeastern Brazil, northern Chile), plotted against the average cloud fraction obtained by all methods. The symbols refer to the following: (0) radiation budget analysis (Rossow, Garder, Kinsella, Lacis), (4) visible threshold method (Mosher), (6) infrared threshold method (Mosher), (7) dynamic cluster analysis of two-dimensional radiance histogram (Debois, Seze), and (c) hybrid bispectral threshold method (Minnis, Harrison).

Seasonal Cycle Analysis

The Climate Group has addressed the timely question of whether General Circulation Models are capable of simulating the global seasonal cycle by performing a 24-month simulation in which all boundary conditions (solar insolation, sea surface temperature, snow/ice cover and soil moisture) were prescribed from climatology as a function of time of year. The atmospheric response was computed from an improved version of the GLAS Climate Model referred to as the Seasonal Cycle Model (SCM). The analysis carried out to date (see figures) indicates that the SCM successfully simulated the very large winter-to-summer change. A large array of diagnostic quantities (including spatial and temporal variances and covariances, spectra, etc.) is being used to study the performance of the SCM, and to compare it to observations. With the advent of FGGE and other Southern Hemisphere data, it is now possible to critically examine the behavior of the SCM in the Southern Hemisphere, an area which has generally received less than adequate attention by modeling groups.

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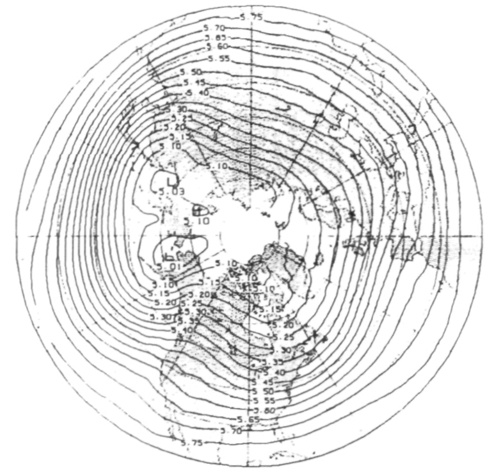
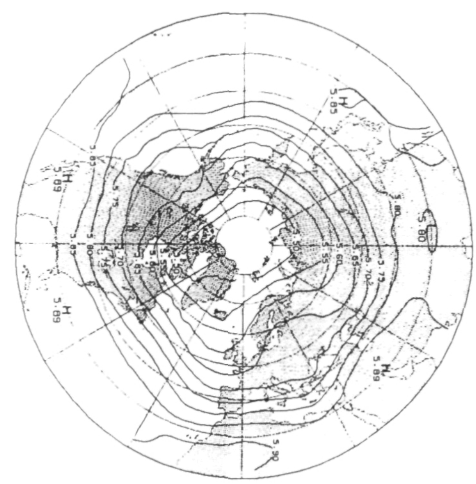


The 500 mb geopotential height in the Northern Hemisphere, averaged over two winter (Dec.-Jan.-Feb.) seasons, in units of 1000 m. The contour interval is 50 m.



The 500 mb geopotential height in the Northern Hemisphere, averaged over two summer (June-July-August) seasons, in units of 1000 m. The contour interval is 50 m.

Cloud Modeling in GCM's

A thorough evaluation of the ability to simulate cloudiness in GCM's was begun during the last year. Preliminary results indicate a tendency of the GLAS Climate Model to predict an unrealistically large amount of low-level cloudiness and, consequently, too high planetary albedo. Two reasons for this were identified: unrealistically large evaporation over land tends to saturate the lowest layers of the model, and an inadequate representation of turbulent and convective processes results in relatively small vertical mixing of water vapor. The use of a more realistic formulation of evaporation over land has significantly improved results, and further improvements may be expected with the new generation of evapotranspiration models currently under development at GLAS. A dramatically improved cloudiness simulation was produced in early tests of a version of the UCLA General Circulation Model currently being installed at GLAS. This generally very successful simulation was attributed to the advanced turbulence and convection formulations used in that model. Work on more sophisticated schemes for modeling stratocumulus and cumulus-related cloudiness is currently in progress.

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Chemistry

Lidar Measurement of Atmospheric Constituents

Despite a considerable increase in the attention given to atmospheric chemistry during the last decade, progress is still limited by the paucity of trace constituent measurements. Lidar appears to be a very promising technique for detection and measurement of these compounds. In particular, lidar is capable of measuring full diurnal variation of trace species, measuring at altitudes not accessible to the host platform, and of measuring in air that is well removed from the instrument platform and hence, free from self-contamination.

A balloon-borne lidar system has been developed which measures the stratospheric hydroxyl radical by excitation of fluorescence in the radical with subsequent detection of the fluorescence, and in addition, measures ozone by determining the relative attenuation of Rayleigh scattered light at two wavelengths. Figure 1 shows an ozone altitude profile measured by the lidar (points with 2σ error bars) compared with that obtained by an *in situ* UV absorption instrument (the continuous plot). Agreement between the two instruments is reasonably good, but the *in situ* instrument is subject to self-contamination and is limited to measurement at the balloon altitude. To date the hydroxyl radical has been measured only in the upper stratosphere. Improvements in the lidar are underway which will permit measurement of the extremely low quantities of hydroxyl (0.1 to 1 ppt) thought to be present in the lower (20 to 30 km) stratosphere.

The gondola is shown in Figure 2. The lidar portion of the instrumentation resides on the three-tiered structure mounted at the center. The frequency doubled dye laser producing several millijoules at 282 nm with a bandwidth of 0.002 nm is located on the top shelf. The central tier holds beam transmitting and receiving optics and the lower level houses the laser power units, the signal processing system, and the environmental control unit. In flight the lidar is enclosed in a pressurized, thermally insulated dome not shown. Experimental flights are slated for this instrument to investigate the rapid diurnal variation of hydroxyl radical at sunrise and sunset, the spatial variation of hydroxyl in the upper stratosphere and mesosphere, and the horizontal variation of the ozone altitude profile.

Laboratory studies are underway to develop measurement capabilities for additional species including NO, NO_2, H_2O and SO_2. A variety of devices needed for lidar such as dye lasers, wavelength meters, and Raman shifters for frequency synthesis are also under development in the laboratory.

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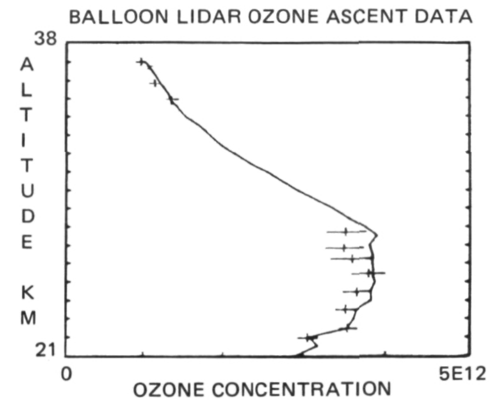
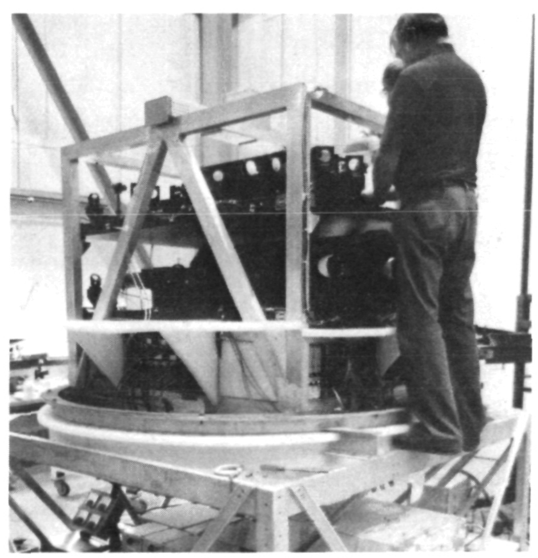


An ozone altitude profile measured by the lidar compared with a UV absorption instrument measurement.



The gondola showing the lidar instrumentation, the frequency doubled dye laser, beam transmitting and receiving optics, the laser power units, signal processing system, and environmental control unit.

Tropospheric Photochemistry

Research on tropospheric photochemistry is directed towards improving our understanding of the relationships between observed trace species concentrations and the physical, chemical, and biological sources and sinks which influence these concentrations. The program consists primarily of the development and use of mathematical models. Present emphasis is on the use of 1-D and 2-D models to investigate the general features of the global distribution of selected trace.

A study of the effects of wet deposition episodes on the variability of HNO_3 concentrations was completed. This calculation indicated that relatively large errors (factor of two in the loss rate) may occur when the continuity equation describing nitric acid variations is averaged over a period which includes precipitation. Our previous work in this area was concerned with estimating the variability of odd nitrogen concentrations assuming that the detailed history of precipitation events was known. In large-scale modeling of trace species which are subject to wet deposition, it is impractical to follow the details of every precipitation event. Some method of determining appropriate mean loss rates is required. Loss coefficients based on the statistics of wet and dry periods for a given region are available from other studies, but the potentially large errors due to averaging nonlinear terms in the species continuity equations have not previously been pointed out. The choice of an appropriate scavenging coefficient for steady-loss calculations must be made with care, considering both the statistical distribution of wet and dry periods which the model is attempting to simulate and the probable magnitude of errors incurred by averaging the continuity equations for chemical species.

A new approach to modeling tropospheric trace species, based on Monte Carlo methods, has been initiated. The first calculations using this approach were to the vertical distribution of odd nitrogen components NO_x ($NO + NO_2$) and HNO_3. At each altitude in the troposphere molecules of NO_x and HNO_3 are subject to chemical transformation, displacement due to advection or eddy diffusion, loss due to wet or dry deposition, and creation in electrical discharge. The relative probabilities of occurrence of these processes, used in the vertical profile calculations, are estimated from chemical and physical parameters and from precipitation statistics. The parameters which influence trace species concentrations are characterized by variabilities as well as by mean values. Precipitation, temperature, wind velocities, and source magnitudes might conceivably have similar mean values in different tropospheric regions while possessing substantially different ranges of values. The Monte Carlo approach has the advantage of permitting a direct estimate of mean concentrations and of concentration variability resulting from either actual variability or uncertainty in physical parameters. In addition, since the continuity equations are not solved directly, errors due to averaging nonlinear terms are not incurred by this approach. Comparison of measured concentrations and calculated values will be facilitated if an estimate of an acceptable range of modeled values is obtained in addition to the calculated mean.

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Nimbus-7 NO and SO_2 Results

The Solar Backscattered Ultraviolet Instrument (SBUV) on Nimbus-7 is operated 1 day per month in a spectral scan mode in which it scans from 160 nm to 400 nm at 0.2 nm steps. By measuring the intensity of a series of nitric oxide gamma band fluorescence features in this wavelength range we can measure the amount of nitric oxide in the upper stratosphere and mesosphere. Previous measurements of NO have been made by up-looking rocket instruments in the mesosphere and as such were point measurements, but by making a nadir NO measurement from a satellite we can determine the global and seasonal behavior of NO. Also, we have been able to observe the spread and disappearance of an SO_2 cloud from the El Chichon volcano by monitoring SO_2 absorption band features between 300 nm and 320 nm. These observations are useful in understanding the mechanism by which SO_2 is converted from gas to aerosol.

The background of atmospherically scattered sunlight normally masks the much weaker nitric oxide gamma band emission, but we have developed a technique for discriminating these emission features. We calculate a theoretical spectrum for a model atmosphere that includes only Rayleigh scattering and absorption by ozone and oxygen and subtract the calculated radiances from the measured radiances. The simple model accounts for the bulk of the variation between 200 nm and 300 nm and the difference plot clearly reveals features not included in the simple model, such as NO gamma band emission.

Emission features are seen at wavelengths corresponding to the vibrational transitions v′v″ – (10), (22), (00), (01), (02), (14), (03), and (15). Nitric oxide is inferred by measuring the absolute intensity of the (10) and (02) bands relative to the adjacent background and relating this intensity to total NO above 45 km. The (14) band is used to infer NO above 50 km. We have processed data from September 1979 and found a fairly uniform distribution of NO of about 7×10^{14} molecules per square centimeter above 45 km altitude, but decreasing to 4×10^{14} at 70°S. Data for the entire first 2 years will be processed soon.

During a solar proton event (SPE) high energy protons enter the atmosphere and produce large amounts of NO. There have been at least seven significant SPE's this solar cycle. We have spectral scan data for July 20, 1982, just 7 days after a large SPE, that shows evidence of enhancement of NO emission. Data more closely following an SPE would be more valuable since most of the NO should have disappeared after 7 days. Data should soon be available from 1 day after an SPE in January 1982. It would be very useful to be able to directly link an increase in NO to a specific geophysical event such as an SPE.

In addition to measuring NO, we can also measure SO_2. A series of SO_2 absorption bands between 300 nm and 320 nm are clearly observed in spectra taken over the equatorial Pacific on April 15, 1982, 2 weeks after the eruption of El Chichon. The strength of these absorption bands gives the column SO_2 amount. A maximum of 24 milli-atm-cm of SO_2 was measured on April 15, and we can measure as little as 1 milli-atm-cm. Spectra made on May 9, 1982, show that almost all the SO_2 had disappeared. This is a very important observation since the previously accepted mechanism for the conversion of SO_2 to aerosols predicted a lifetime of months, and we now have evidence for a competing mechanism that predicts a lifetime of weeks.

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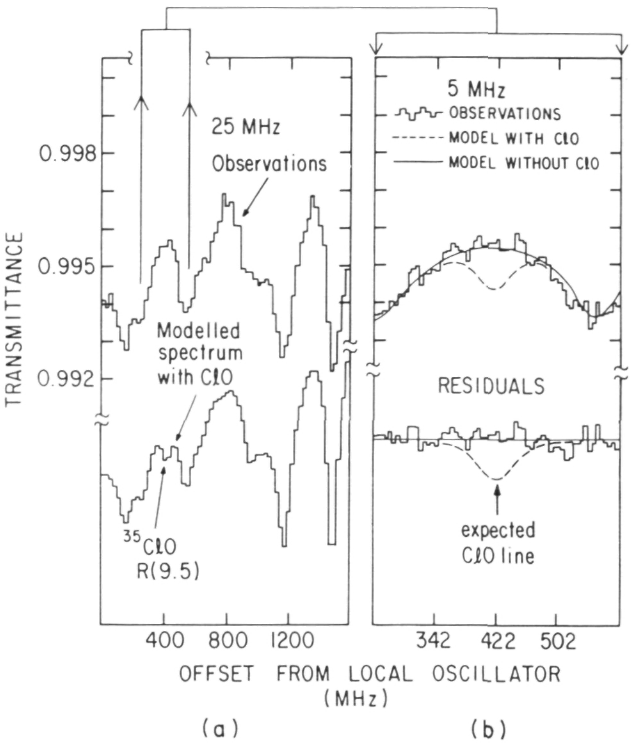
The Chlorine Monoxide Problem

Chlorofluorocarbons are important and widely used industrial chemicals, but current understanding of stratospheric photochemistry indicates that their release may deplete the ozone layer. Chlorine monoxide is believed to be a key intermediary in this process, and measurement of its stratospheric abundance is therefore particularly important.

Recently, Goddard scientists have reported results (Mumma et al. *Science* 221, 268, 1983) which show that current understanding of stratospheric $C\ell O$ may be seriously incomplete. A group headed by Dr. Michael J. Mumma has observed the infrared (12 μm) transmittance spectrum of the Earth's atmosphere in absorption against the Sun. The measurements were made using the McMath Solar Telescope at Kitt Peak National Observatory. The Goddard group developed and used an infrared heterodyne spectrometer to make measurements using ultra-high spectral resolution ($\nu/\Delta\nu \sim 10^7$). In these measurements the solar absorption spectrum was null-balanced against the continuum spectrum of a laboratory blackbody source. This null-balanced technique allowed spectra to be obtained with signal-to-noise ratios greater than 10^4, resulting in extraordinary sensitivity to stratospheric trace species. Using this new technique the Goddard group measured previously undetected lines due to stratospheric HNO_3 and other species. $C\ell O$ lines, however, did not appear in their atmospheric spectra, implying that its stratospheric abundance is about seven times less than currently accepted values. Since the Goddard instrument is routinely used to observe weak astronomical sources and to measure spectra of



Infrared transmittance spectra of the Earth's atmosphere, at high spectral resolution (left) and at ultra-high resolution (right). The expected line due to stratospheric CℓO does not appear, implying that its abundance is greatly reduced from currently accepted values.

molecules (including CℓO) in the laboratory, these results are particularly difficult to reconcile with current understanding of stratospheric chlorine chemistry. Given the current theories, they imply that the release of chlorofluorocarbons may be significantly less important for the destruction of stratospheric ozone than is presently thought.

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Physics

Severe Storm Research

Meteorological uses of satellite observations have been important to meteorological predictions since the first Tiros satellite was launched over 20 years ago on April 1, 1960. Earlier usage of satellite observations concentrated on larger (synoptic) scale features such as hurricanes and frontal systems identified by their characteristic cloud patterns and the intervening fair weather regions. With the advantage of satellite observations, global observations (previously impractical due to cost of observing over vast ocean and uninhabited regions) became a reality. With the increasing space and time resolution provided by improved instrumentation, use of a wide variety of wavelengths for observing and development of geosynchronous satellites, even extensive subsynoptic or mesoscale meteorological observations became practical. Previously, such smaller scale observations were accomplished only at great expense over very limited areas for very limited time periods and were extremely useful, primarily for research purposes. At present, there is an ever-increasing interest in studying meteorological observations from satellites, aircraft, balloons, and ground facilities in order to develop a most cost-effective combined observation system to support predictions which are most useful to our society. Severe storms are of primary interest to our society since they present such a great potential for death and property damage. These storms are most frequently a mesoscale occurrence embedded in, and influenced by, a synoptic-scale atmospheric environment. Conversely, the small-scale storm is also often an important influence on this large-scale environment.

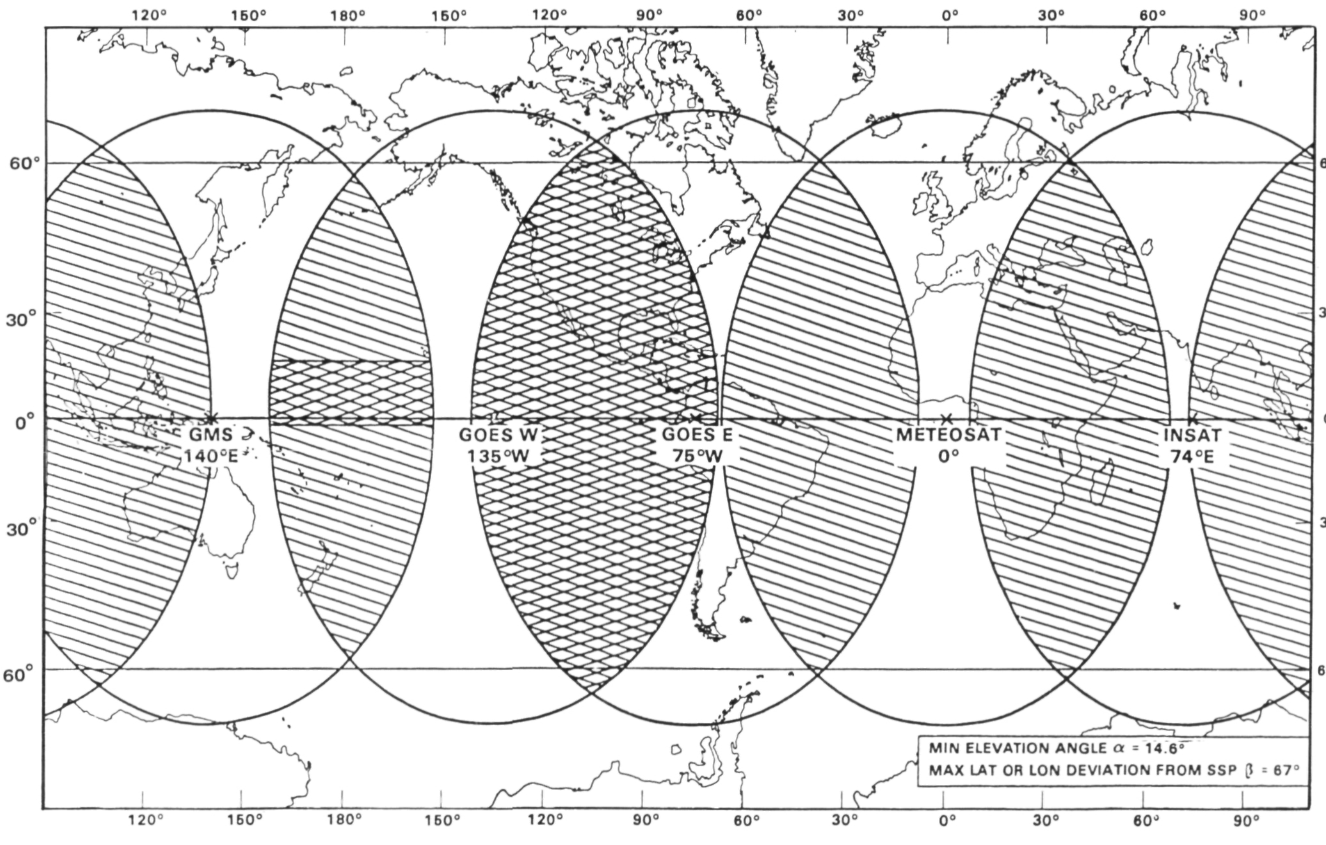
One effective means of research in severe storm prediction is carried out by an interactive process of parameter selection (based upon current physical knowledge), observation, analysis, research, and modeling. These processes are carried out concurrently and must be interrelated frequently. If an optimal observing system of useful parameters is applied to a model which optimally incorporates our current physical knowledge, the result should be the best forecast possible, given our present state of knowledge. Goddard research in severe storms is directed toward developing a better physical understanding of severe storm mechanisms in order to improve our storm model observation techniques and parameter selection. Two powerful tools are routinely used in our research: (1) an interactive computer display facility is available to map, overlay, compare, and otherwise analyze data from a

variety of sources; and (2) models uniquely developed to accommodate satellite data and to include mesoscale atmospheric processes are being developed in order to verify research results, study parameters for observations, and to facilitate inclusion of satellite data into the prediction process.

In our research, satellite data (visible imagery data, IR imagery data, microwave sounding, and stereo observations) are combined in a variety of ways with each other and with nonsatellite data to verify and improve our parameter selections, parameter definitions, and related algorithms, and to learn more about mesoscale and cloud-scale atmospheric physics for use in model improvement. A few of our specific research efforts are subsequently described.

Satellite Stereo Observations: The capability of making stereoscopic observations of clouds from meteorological satellites is a new basic analysis tool with a broad spectrum of applications. In 1978, Bryson and des Jardins developed digital processing techniques for remapping stereo images. This made possible precision height measurement and spectacular display of stereograms. In 1980, the Japanese Geosynchronous Satellite (GMS) and the U.S. GOES-West satellite were synchronized to obtain stereo over the central Pacific. Recently, images from a Low Earth Orbiter (LEO) have been mapped to the coordinate system of a Geosynchronous Earth Orbiter (GEO). Stereoscopic cloud height measurements have been obtained which promise to have quality comparable to previous all GEO stereo. Thus, it is now possible to obtain stereoscopic observations worldwide from combinations of operational GEO and LEO satellites.

Stereoscopy from satellites has many advantages over infrared techniques for the observation of cloud structure because it depends only on basic geometric relationships. Digital remapping of GEO and LEO satellite images is imperative for precision stereo



Areas of stereoscopic cloud height measurement from operational geosynchronous satellites.

height measurement (+500 m) and high quality analyses. Applications of the satellite stereo include: 1) cloud top and base height measurements, 2) cloud-wind height assignment, 3) vertical motion estimates for convective clouds, 4) temperature versus height measurements when stereo is used together with infrared observations, and 5) cloud emissivity measurements when stereo, infrared, and temperature sounding are used together.

The simplest way to observe clouds stereoscopically is with two identical scan-synchronized geosynchronous Earth orbiters. In this case, height is a simple function of parallax over a large part of the common field of view of the two satellites. Time sequences of stereo analyses like these can be used to measure cloud top ascent rates and estimate the intensity of convection. They can also be used to obtain accurate heights for winds obtained from sequential observations of cloud motions.

The only place where this kind of stereo can be done at present is during daylight hours in the common field of view of the two U.S. GOES satellites, which is the largest crosshatched area shown in the figure. Even though the Japanese GMS and the U.S. GOES satellites have different resolutions and scan rates, it is possible to obtain nearly scan-synchronized stereo observations over a fairly large area. The Japanese Meteorological Agency started the GMS image such that GMS and GOES scanned 7.5°N latitude at the same time for several test cases on different days. The crosshatched area in the central Pacific in the figure was scanned by both satellites within 30 s.

VAS Studies: The Visible and IR Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS), which operates from the geosynchronous GOES satellite, has the capability to provide temperature and moisture soundings through the atmosphere with a relatively fine time resolution and a reasonable space resolution. Extensive research efforts are underway to use the VAS for monitoring the prethunderstorm environment. The ultimate goal is to determine the optimal space and time resolution of such VAS data and to use it effectively in predictive models which deal with development of severe storms. Recent results have clearly demonstrated the ability of VAS to measure low-level water vapor, upper-level water vapor and sea surface temperature. The utility of these water vapor measurements for monitoring areas of convective instability has been demonstrated. These and other results indicate a considerable potential for VAS as an important data source for improvement of conventional forecasts as well as for short-term forecasts of severe local storms.

Software and Model Development: In cooperation with the Information Extraction Division at GSFC, a General Meteorological Software Package (GEMPAK) has been developed for use with the man-computer interactive system mentioned previously, Atmospheric and Oceanographic Information Processing System (AOIPS). This software makes it possible to combine data from a wide variety of sources to use in analyses and diagnostic studies, using the computer facilities in an interactive mode. Improvements in our research prediction models are being made regularly, as new knowledge becomes available concerning cloud morphology and as we learn to better optimize data from new observations.

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Surface Radiation and Tropical Circulation

The large pressure difference between the South Pacific High and the Indonesian Low causes strong trade winds off the coast of Peru and along the Equator, which in turn causes the cold water to advect from the south and to upwell from below. The water in the eastern equatorial Pacific and along the coast of Peru is therefore colder than the water to the west. Once every 3 to 5 years, the pressure difference decreases and so do the trade winds. The water temperature off the coast of Peru is several degrees higher than normal and rainfall in the normally dry central Pacific and South American coast is copious. The event, which is known as El Nino, is not only confined to the tropical Pacific but also

related to the worldwide inadvertent weather pattern with floods and droughts occurring in various countries. Although it is commonly accepted that the relaxation of the trade winds is the main cause of El Nino, it is far from clear what causes the winds to relax.

Among the various possible causes for the trade winds to weaken is the solar heating of the ocean. During the months preceding El Nino, the winds are known to be intense. There are more clouds than normal in the western tropical Pacific, while the central and eastern equatorial Pacific is less cloudy than normal. Such a cloud anomaly, if it persists over a period of several months, could cause the sea surface temperature (SST) in the central and eastern equatorial Pacific Ocean to increase slightly, perhaps by only 1°C, with a corresponding change in zonal and meridional temperature gradients. Since the tropical flow is quite sensitive to the SST gradient through the thermal wind relation, the abnormally strong solar heating could trigger a series of positive feedbacks and eventually lead to an El Nino event.

In order to explore the role of surface radiation on the large-scale atmospheric circulation, a series of monthly mean surface radiation budgets stretching from January 1970 to February 1978 has been computed using the efficient radiation routines we have developed over the past several years. The data inputs to the radiation calculations are the surface temperature and humidity from ship reports, cloud parameters from satellite observations, and temperature and humidity profiles from climatology. Spatial and temporal correlations are further established for various radiative terms. These sets of data provide the information on the strength and variability of surface heating through solar and IR radiation. In progress now is a study of correlations among the variations in surface radiation, sea surface temperature and trade winds to assess the role of surface radiation as a forcing mechanism of El Nino.

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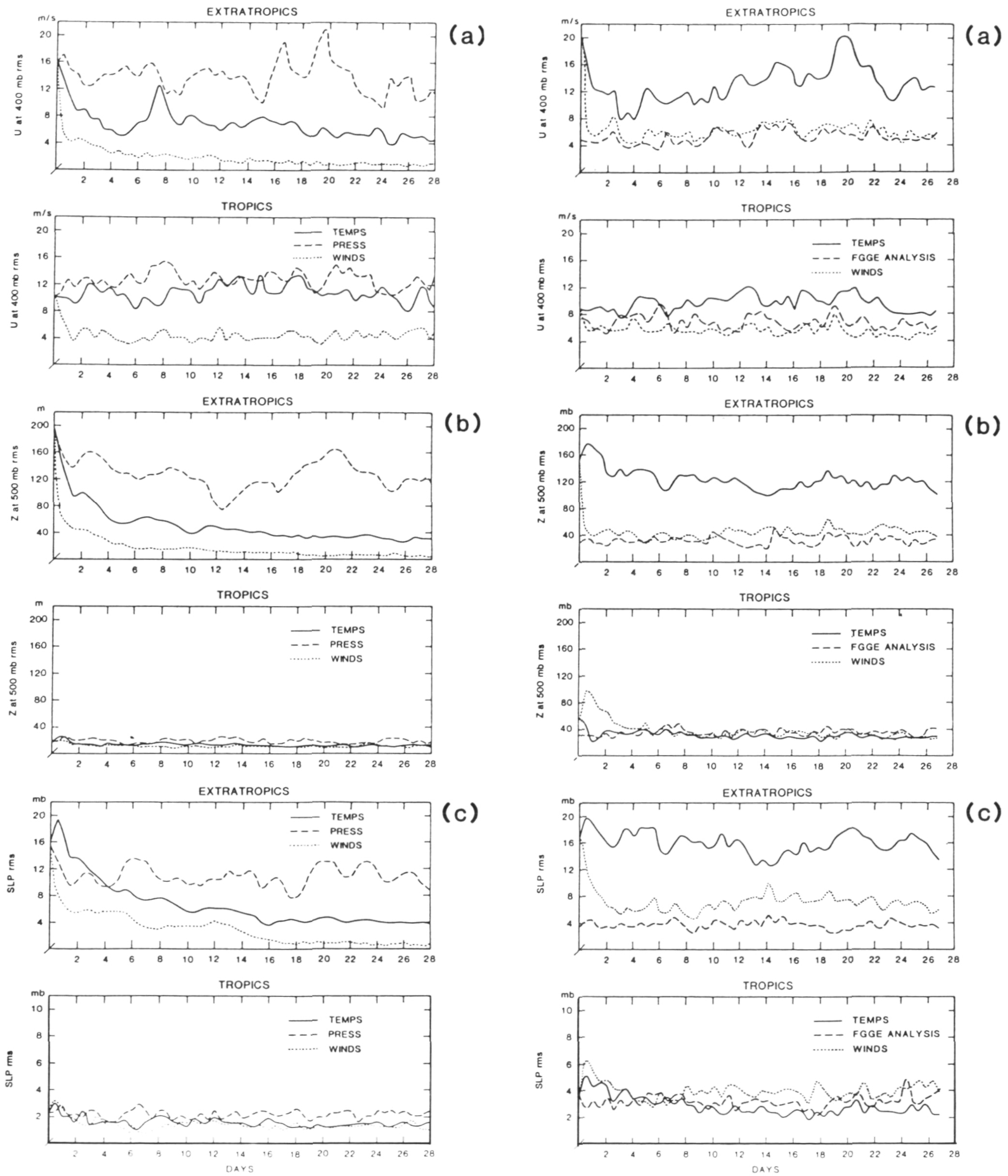
Simulation Studies of Wind Profiles from Space

Recent technological developments in coherent laser systems indicate the ability to measure winds from space. In addition, feasibility studies carried out by RCA and Lockheed show that Shuttle and operational satellites are capable of providing measurements from such wind systems. However, substantial development costs are entailed thus raising the need for realistic simulation studies to assess the relative importance of wind profiles compared with improving the measurements of other meteorological variables. In this regard, a preliminary series of experiments were conducted on the Cyber 205 to obtain broad estimates of the relative impact of individual meteorological observing systems on analysis and weather forecasting. Two such highly idealized experiments were performed. The first set used perfect simulated data fields obtained from a long GCM model history run that was the same as that used for assimilation and forecasting. The second set of experiments used real data fields obtained from the operational NMC analysis archives. In both experiments, verifications of analyses and forecasts were made relative to the respective fields from which the data were simulated.

Figures 1a, 1b, and 1c compare the asymptotic rms error levels in the 12-hour first-guess fields (forecasts) before data insertion for the 400-mb zonal winds, 500-mb geopotential heights and sea level pressures, respectively, in tropics and extratropics for simulated data. Figures 2a, 2b, and 2c show the respective asymptotic rms error levels obtained from real data. In this figure, surface pressure data alone are not shown since, as the results in Figures 1a, 1b, and 1c, they have little effect on the forecast. Shown are the 12-hour forecast fields called "FGGE" made from the GLAS analysis cycle using the full FGGE observing systems.

The conclusions drawn from this study are:

- Global accurate measurements of wind profiles make by far the largest single improvement in reducing the 12-hour forecast errors in numerical weather prediction compared to temperature and pressuring observing systems;



Twelve-hour forecast errors.

- Surface data measurements alone have relatively little impact on 12-hour forecast errors;

- Current real temperature and pressure data alone in extratropics hardly have any improvement on the 12-hour forecast errors while the wind profiles alone improve 12-hour forecasts almost as much as the entire FGGE observing system. Prognostic charts not shown here support the statistical conclusions.

In summary, these limited studies strongly indicate winds are the most important meteorological variables needed for weather prediction. Future tests are planned for the coming year that will assess their relative importance with respect to their incorporation with the complete global operational observing systems.

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Cloud Radiation Experiment

Three instruments designed for remote sensing of cloud physical properties were flown on a high-altitude aircraft for a 2-week period in the Cooperative Convective Precipitation Experiment (CCOPE). The instruments were: a multispectral cloud radiometer (MCR), a cloud lidar system (CLS), and an advanced microwave moisture sensor (AMMS). The MCR is a 7-channel scanning radiometer designed to use the reflectance properties of clouds in the near-infrared water vapor absorption windows and emission in the thermal infrared window to remotely sense several cloud parameters. These parameters include cloud optical thickness, cloud top pressure altitude, volume scattering coefficient, particle phase, effective particle size, and cloud top temperature. The CLS is a nadir pointing dual wavelength (1.06 and 0.53 μm) and dual polarization lidar which is used to remotely sense cloud top geometrical altitude, phase (through the depolarization ratio) and either volume extinction coefficient or optical thickness, depending upon whether the cloud is optically thick or thin. Finally, the AMMS is a 4-channel (92 GHz and 183 GHz) scanning radiometer which is sensitive to the columnar amount of cloud and the vertical distribution of water vapor.

Algorithms to infer the cloud physical parameters from measurements of MCR have been developed for an homogeneous extended cloud. These algorithms have been applied to CCOPE data.

In cloud top altitude determination, a combination of a set of simplified methods is searched to estimate the amount of photon penetration. Results indicate that the photon penetration effect can be as large as several kilometers.

In cloud particle thermodynamic phase determination, the algorithm has been developed to infer particle phase and size simultaneously to avoid ambiguity. The algorithm is good in determining phase and size for small particles. It breaks down for large particles. The most probable reasons are the shape effect, the nontransparency, the size distribution, and the detailed structure of the phase function of large ice particles. We are trying to improve our algorithm to take some of these effects into account.

In cloud top temperature determination, the intensity is directly used in the inverse Planck function to obtain the equivalent blackbody temperature. Using local sounding, the cloud top geometrical altitude can be derived.

Generally, there is good correlation between the MCR-derived cloud top altitude and that derived from lidar. The variation is within ±1 km. In the case of thin cloud the variation is much larger. The emissivity less than unity should be used.

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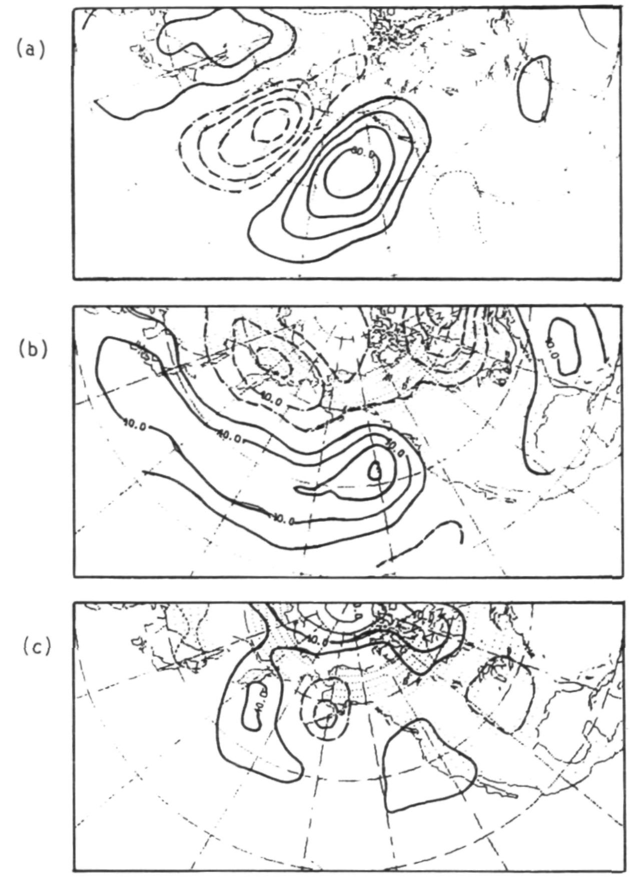
Low-Frequency Tropical-Midlatitude Interactions

Cloudiness fluctuation associated with possible wintertime tropical-midlatitude interaction on intermediate (10 to 50 days) time scales is investigated using 7 years (1974 to 1981) of outgoing long-wave radiation data. We make use of correlation statistics, composite and time-longitude analyses to study the relationships between several key features revealed by earlier teleconnection studies. These features include the monsoonal cold surge over East Asia, blocking-like development over the North Pacific, convection over the Borneo-Indonesia maritime continent and the equatorial central Pacific, and possible downstream influence over North America. Midlatitude cloud bands associated with cold surges over East Asia originating from Euro-Asia are seen to be strongly coupled to equatorial cloud clusters propagating eastward from the Indian Ocean to the central Pacific. The latter is likely to be associated with the tropical 40- to 50-day large-scale Kelvin-wave-like oscillations known to be present over the same regions. The evolution of the interactions is obtained from composite analyses using as reference the phase of the 40- to 50-day oscillation in the Equatorial Central Pacific Convection (ECPC). Results show that these eastward-propagating coupled systems frequently lead to enhanced ECPC. Major flare-ups in ECPC are either caused by the passage and intensification of the rising branch of Kelvin-wave-like circulation along the Equator from the east, or by an intensification of the upper-level ridge-trough system over Hawaii which penetrates into the deep tropics over the central Pacific, or by a combination of the above two mechanisms. These results are now confirmed in a study of the variation of extratropical geopotential height associated with the ECPC. Prior to major convective flareups in ECPC, midlatitude centers of activity are found over East Asia followed by distinct wave-trains over the Pacific with southwest-to-northeast orientations indicating equatorward energy propagation. Simultaneous with the maximum in ECPC, the height pattern shows a dipole-like structure associated with a deepening Aleutian low. Subsequently, the pattern moves eastward and new centers of the wave train appear to develop over North America, but with much weaker intensity. Comparing the 200 mb and 500 mb horizontal structures, the signals appear to be barotropic in nature. The orientation and shapes of the eddy suggest an exchange of midlatitude eddy energy and tropical heat of condensation over the central Pacific. The coherence in the progressive eastward migration between the midlatitude centers of action and that of the tropical convective system suggests a near-global-mode oscillation encompassing a large part of the tropics and the midlatitudes. This mode of interaction appears to be consistent with the theory of barotropic energy dispersion on the sphere.



Geopotential height fluctuation at approximately 7 to 8 day intervals (a) before, (b) during and (c) after major flareup in large-scale convection over the near-equatorial central Pacific.

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Thermospheric Superrotation Revisited

The phenomenon of thermospheric superrotation has puzzled the scientific community for 2 decades. Based on satellite drag analysis, there was indirect evidence suggesting that the uppermost region of the atmosphere is rotating 20 to 40 percent faster than the Earth; but none of the many mechanisms proposed, nor their combined effects, have come close to explaining this magnitude. The recent *in situ* wind measurements with the WATS experiment on the Dynamics Explorer-II satellite have now provided, for the first time, a reliable data base to address this long-standing problem. At altitudes near 300 km, the superrotation rate is found to be small, <3 percent of the Earth's rotation. This is only a fraction of the values inferred from satellite drag observations, but still within their error bars. Such superrotation rates can be understood in terms of ionospheric accelerations associated with the diurnal solar tide. The zonally symmetric, solar differential heating due to radiation absorbed at low latitudes and Joule dissipation at high latitudes do not significantly affect the prevailing motions, but can produce the large variations in temperature and composition observed on the Atmosphere Explorer satellites.

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UPPER ATMOSPHERE

Upper Atmosphere Research

GSFC's activities in upper atmospheric research are devoted to expanding our understanding of the radiative, chemical and dynamical processes which determine the state of the stratosphere and mesosphere. A great deal of progress has been made in each of these individual areas, and it has become quite clear that the frontier of understanding now lies in the close coupling among the radiative, chemical and dynamic aspects of the upper atmosphere. The GSFC program in upper atmospheric research includes experimental measurements, interpretation of existing satellite data, and theoretical studies. Experimental efforts include: a lidar fluorescence system capable of measuring the hydroxyl radical (OH) and other constituents from a balloon or aircraft platform; several instruments which measure ozone *in situ* from balloons and/or rockets; balloon, rocket and satellite measurements of the ultraviolet solar irradiance and its attenuation and scattering in the atmosphere; the Backscatter Ultraviolet Experiments (BUV's) which have flown on Nimbus-4 and Nimbus-7 and are planned for the Tiros series and UARS. The data interpretation effort includes: derivation of winds and other diagnostics from stratospheric temperature data which are used to examine the mean dynamical state of the stratosphere and its interannual variability; a continuing search for relationships between solar variability and the state of the stratosphere, particularly the upper stratosphere ozone concentration; correlation studies of upper stratospheric ozone and temperature; studies of the effects of solar proton events on upper stratospheric ozone and nitric oxide; and attempts to use the data from satellites and *in situ* measurements to determine the long-term changes, if any, in the stratosphere. Theoretical efforts are focused on the attempt to integrate radiative, chemical and dynamical processes into our overall understanding of the upper atmospheric system. They are closely coupled to data interpretation efforts and include development of a hierarchy of models to quantitatively assess the relative importance of a variety of processes and their interconnections. In addition to the SBUV instrument on

the Upper Atmosphere Research Satellite (UARS), GSFC has theoretical Principal Investigators on the science team who will use the data from that satellite in a manner closely coupled with the theoretical modeling effort drawing upon the data interpretation experience from the work presently underway. The overall goals of this effort include the understanding of the radiative-chemical-dynamical coupling of the upper atmosphere as well as the investigation of the possible coupling of the upper atmosphere to the lower atmosphere and climate system.

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The UARS Solar Backscatter Ultraviolet Spectral Radiometer

The Solar Backscatter Ultraviolet Spectral Radiometer (SBUV/2U) is designated as a mission of opportunity instrument in the UARS payload. The chief function of this instrument is to continue acquisition of a global scale data base for upper stratospheric and total ozone begun by similar instruments on Nimbus satellites in the 1970's and to be continued in the 1980's on Tiros spacecraft. Much of the original interest in the stratosphere arose because of concerns that man's activities could lead to a chemical depletion of the Earth's ozone layer, thereby increasing the flux of biologically harmful ultraviolet radiation reaching the ground. While such fears have diminished somewhat with improved theoretical understanding of the processes that control the ozone layer, there is now an increased interest in studies of possible long-term changes in the atmosphere. The origins of these changes lie in solar variability, evolution inherent in the coupled Earth-atmosphere system, and the continued likelihood of anthropogenic effects. The study of such phenomena requires acquisition of a data base of uniform quality that extends over many years and which, of necessity, involves comparison of results obtained from a series of essentially identical instruments.

In this context the backscatter ultraviolet system emerges as a class of instrument which has a demonstrated capability for long-term operation, yielding ozone profiles over an altitude region of great scientific interest. The UARS-SBUV/2U experiment is a follow-on to three optically identical instruments planned for launch beginning in 1984 which in turn complement similar, though less sophisticated, systems in use since 1970. In view of the above, the prime objective of the SBUV/2U effort is to provide a data set consisting of vertical profiles of ozone and total column ozone for use in scientific studies of long-term atmospheric behavior in conjunction with other backscatter ultraviolet instruments. An additional objective of the experiment is to acquire information on the ultraviolet solar irradiance, the diffuse atmospheric radiation field, and fluorescent emissions from nitric oxide for use in conjunction with other data obtained by instruments on the UARS mission.

The SBUV/2U hardware consists of two distinct units. The sensor module contains all monochromator components, a cloudcover radiometer for surface albedo measurements, redundant mercury lamps for in-flight wavelength calibrations, the photomultiplier tube, electrometer, and the diffuser plate assembly. The sensor module is connected by a cable to the electronics and logic module which houses all spacecraft interface circuits, receives commands from the ground, and transmits all data. The instrument was designed and will be built by Ball Aerospace Systems Division.

The end product of the UARS-SBUV/2U effort, taken in conjunction with its predecessors, will be an upper stratospheric and total ozone data base covering more than one solar cycle. Analysis and interpretation of this unique data base will provide for an understanding of long-term stratospheric behavior that surpasses that which has been possible in the past.

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Chemistry

Hydrocarbons in the Lower Stratosphere

Calculations have shown that the nonmethane hydrocarbon ethane has a sufficiently long lifetime against photochemical destruction to be transported to the upper troposphere and lower stratosphere, where it is transformed photochemically into other products. One of these new molecules, peroxyacetyl nitrate, is an important reservoir for odd nitrogen in the vicinity of the tropopause. It has also been found that the compound peroxychloroformyl nitrate can be formed in the lower stratosphere by the combination of atomic chlorine, carbon monoxide molecular oxygen and nitrogen dioxide. The expected concentration is not large enough to change the predicted effects of chlorofluoromethanes on stratospheric ozone.

A measurements program has been established to quantify the concentrations and identify the nonmethane hydrocarbons and their photochemical products. Both the techniques of remote sensing infrared and direct grab sampling with gas chromatographic analysis are being employed. The Air Force Geophysics Laboratory is cooperating in the grab sampling effort.

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Ozone Depletion During Solar Proton Events

Near the peak of a solar cycle the Sun sporadically emits very large numbers of high energy protons that enter the Earth's atmosphere in the polar regions (above 60 degrees geomagnetic latitude) producing HO_x and NO_x species which, in turn, catalytically destroy ozone. Since these solar proton events (SPE's) occur in a limited area of the globe, the response of ozone to changes in HO_x and NO_x provide natural experiments for better understanding the chemistry of the stratosphere and mesosphere. We have now analyzed ozone profile data from the Solar Backscattered Ultraviolet Instrument on Nimbus-7 from 1979 to the present and have found clear cases of ozone destruction at 50 and 55 km associated with at least four SPE's: on June 7, 1979; August 21, 1979; July 13, 1982; and December 8, 1982.

The ozone depletion is short-lived, disappearing within hours of the end of the SPE. This ozone response indicates destruction due to an increase in the HO_x species which dominate the ozone chemistry near the stratospause and into the mesosphere. The ambient HO_x species' production is dependent on the solar zenith angle (SZA), being smaller at the higher SZA's. Since the HO_x production by the solar protons is not dependent on the SZA, a larger ozone decrease at the higher SZA's is expected during SPE's. Ozone decreases above the altitude of consideration can also enhance the ozone depletion at that altitude, again with a very strong SZA dependence. During the SPE on July 13, 1982, the largest of this solar cycle, a 15-percent ozone depletion at 50 km and a 27-percent ozone depletion at 55 km were observed at an SZA of 85 degrees. This ozone destruction decreased with decreasing SZA and below an SZA of 70 degrees was virtually nonexistent. Photochemical modeling of the ozone response due to the SPE-produced HO_x species provides good qualitative agreement between theory and observation. The model predicts the strong SZA dependent ozone depletion; however, the observations show approximately twice the ozone decrease predicted by the model.

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Stratospheric General Circulation with Chemistry Modeling (SGCCM)

The goal of the SGCCM project is to model the dynamical and chemical processes governing ozone and its interacting constituents. Because ozone is a

radiatively active, photochemically produced minor constituent, changes in the ozone distribution produce changes in the flow field which may feed back onto the original ozone perturbation. This complexity requires accurate dynamical, radiative and chemical models interactively coupled together.

A first step is the development of a dynamical model of the stratosphere which successfully simulates observed phenomena. Toward this end a grid point general circulation model has been developed which shows considerable skill in stratospheric forecasts. The results of a simulation of a sudden stratospheric warming are described below. The observational analysis used as the initial state for this simulation was performed by the SGCCM group and the Goddard Laboratory for Atmospheric Sciences.

In Figure 1 the observed initial state at 5 mb is shown. Using this data, the model forecasts of geopotential height at day 3 (Figure 2) and day 6 (Figure 3) are shown and compared with observations for the same days. The model produces a good simulation out to day 3 but obvious deficiencies appear by day 6. For example, the twin high pressure systems have rotated counterclockwise too far in the forecast on day 6 compared with observations. This experiment represents the first successful stratospheric forecast out to medium range of these altitudes. The breakdown in the forecast at day 6 is now being investigated; nevertheless, we are very encouraged by this simulation.

Along with the development of general circulation (grid point) dynamics model discussed above there are a number of other ongoing projects in the SGCCM group. They are:

- Continued analysis of multiyear stratospheric general circulation data sets. Interannual variations in the structure and transport characteristics of the stratosphere will be compared for the Northern and Southern Hemispheres.

- Continued development of a spectral transform general circulation model of the troposphere-stratosphere-mesosphere system. This model will be used for long-term studies of the stratosphere as well as dynamics-chemistry-radiation interactions within the middle atmosphere.

- Development and intercomparison of fast radiative transfer algorithms for the general circulation models.

- Development and implementation of chemistry packages suitable for modeling the stratospheric-tropospheric system.

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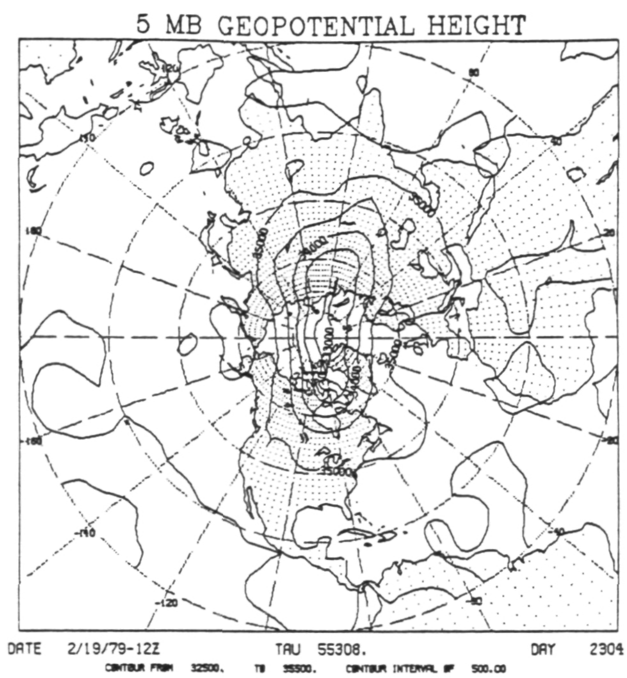
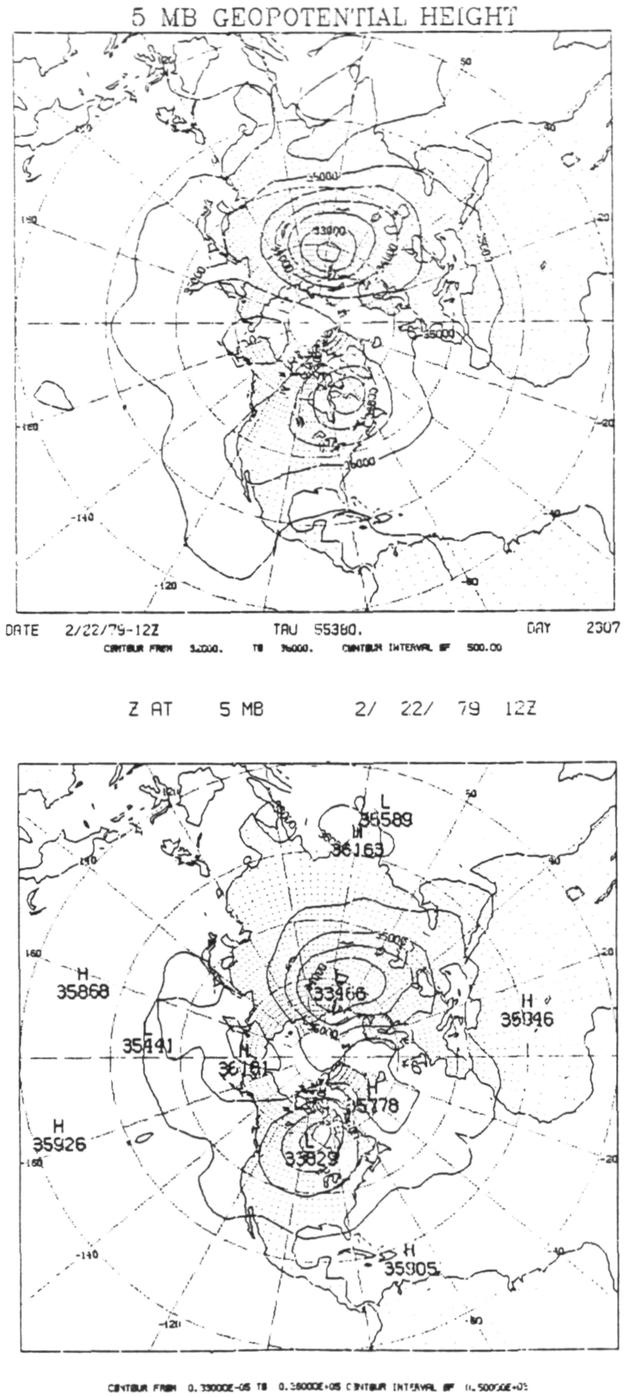


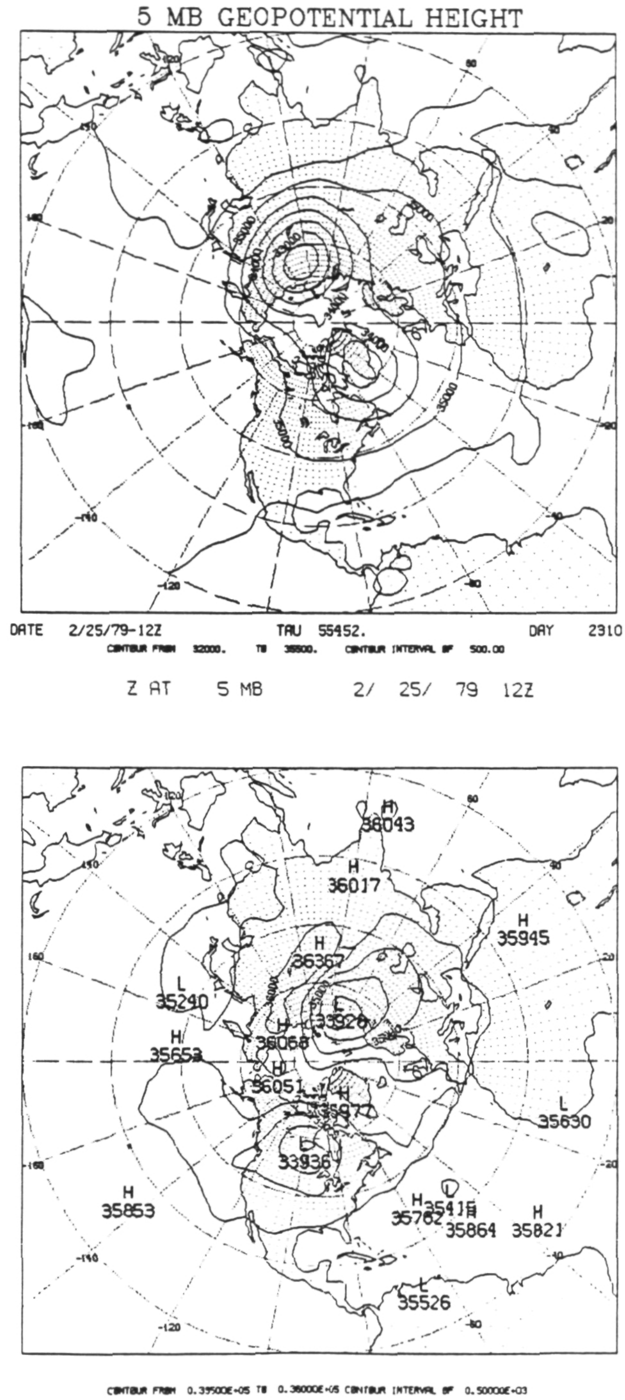
(a)

5 mb (about 37 km) geopotential height (meters) initial state (500 meter contours).



(b)

5 mb geopotential height (meters) forecasted (above) and observed (below) for 3 days after the initial state. (500 meter contours).



(c)

5 mb geopotential height (meters) forecasted (above) and observed (below) for 6 days after the initial state. (500 meter contours).

EARTH SCIENCES

Geodynamics

Estimates of the length-of-day (LOD) have been derived from laser tracking data of the Lageos spacecraft and compared with inferred changes in LOD deduced from atmospheric angular momentum. Six years of data from Lageos and angular momentum beginning in May 1976 have been studied. Earth tidal corrections have been applied to the Lageos LOD at annual, semiannual, monthly and fortnightly periods and both data sets reduced to 5-day averages. Spectral analyses of the 6 years of atmospheric data show very little power below 100 days although short-lived phenomena are clearly evident at times within the data set. Most of the power is in the annual term with a smaller amount at 6 months. The Lageos data set shows much power at the semiannual frequency (even after applying a tidal correction) and is, perhaps, the frequency where the largest difference with the atmosphere appears to occur. In addition, the variation in the Lageos LOD clearly shows that the rotation rate of the Earth is steadily increasing over the 6-year period while the atmospheric momentum shows no discernible secular trend, confirming that very long-term changes in LOD of the solid-Earth are probably caused by motions in the Earth's core rather than the atmosphere. Comparison of the two raw data sets over the 6-year period shows very good agreement, particularly since 1979 when the Lageos tracking data increased significantly in quality. Overall correlation (r^2) of the two data sets is about 0.82 for the entire data span. When all periods greater than 80 days are removed from both data sets, the residual variations remain correlated at about $r^2 = 0.6$ and the comparison suggests that even on time scales as short as 5 to 10 days that the solid-Earth is responding to atmospheric changes. Studies of the hemispheric components of the atmospheric angular momentum suggest that the northern hemisphere dominates in the atmosphere-solid Earth interaction but that the southern hemisphere winds can, on occasion, cause observable changes in the rotation of the Earth.

From 1972-1979 laser ranging measurements to the Beacon Explorer C spacecraft from two tracking stations in California were used to estimate the rate of fault motion presently occurring across the San Andreas Fault system. The results of this San Andreas Fault Experiment (SAFE) suggested a total motion of about 8 ± 2 cm per year was occurring between Otay Mountain, near San Diego and Quincy, in northern California; the stations being on opposite sides of the fault. In 1981 the experiment was repeated using a new site, Monument Peak in southern California, instead of Otay Mountain. More recent laser ranging measurements obtained during the period October 1981 and July 1982 from Monument Peak and Quincy to the Lageos spacecraft were used to derive several estimates of the baseline rate of about 7.4 ± 2.9 cm/yr, in good agreement with the earlier estimates of the motion across the Fault. This result increases the probability that the present-day motion along the San Andreas Fault is larger than the 5.5 cm/yr average derived from sea floor spreading.

Postglacial rebound appears to have been observed gravitationally by the Lageos satellite. Sixty-four observations of the orbital node, made over a 6-year time interval, reveal an acceleration of $(-8.2 \pm 1.8) \times 10^{-7}$ arcseconds/day^2 in the node of the orbit due to a source not presently modeled in the GEODYN orbit determination computer program. This acceleration cannot be explained by the ocean tide with an 18.6-year period, assuming it to be a global equilibrium one. The acceleration appears to be due to postglacial rebound in Laurentide, Canada and other formerly glaciated regions of the Earth. The rebound is causing J_2, the second degree, zeroth order term in the spherical harmonic expansion of the Earth's gravitational potential to decrease at the rate of $(-8.0 \pm 1.8) \times 10^{-19}$ s^{-1}; this in turn causes the observed acceleration in the node. This rate is in good agreement with the realistic L1 Earth model of Wu and Peltier. Modeling the Laurentide ice sheet with L1, which has a lower mantle effective viscosity of 10^{22} poises, gives a predicted rate of change in J_2 of -6×10^{-19} s^{-1}, which is close to the observed

value. On the other hand, their realistic L2 model with its 10^{23} poise lower mantle effective viscosity gives -19×10^{-19} s^{-1} for the rate of change of J_2, which is more than twice the observed value. Thus the effective viscosity of the lower mantle appears to be about 10^{22} poises.

A model utilizing Seasat altimetric data to study oceanic lithosphere mechanical properties has been developed. Using this model, effective lithospheric thicknesses to the seaward side of 5 deep ocean trenches have been generated. The results show that lithospheric thickness increases with age of the lithosphere, in good agreement with existing rheological models. In fact, these results, derived for the first time from satellite altimetric data, agree more closely with the rheological models than do results obtained from conventional bathymetric data.

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Crustal Dynamics

The thrust of GSFC's crustal dynamics research is to utilize space methods and technology to make precise geodetic measurements of crustal motion, deformation and Earth rotation parameters. The analysis of these data is expected to lead to an improvement in our knowledge and understanding of the Earth's dynamic motions and the forces that produce earthquakes.

Observations with Very Long Baseline Interferometry (VLBI) have now been made over a 6-year period between the Haystack Observatory in Westford, Massachusetts, and the Owens Valley Radio Observatory (OVRO) in eastern California. Analysis of these data shows no detectable change in this baseline greater than 0.2 cm/yr. The measurements of this baseline, as well as baseline from these two observatories to Fort Davis, Texas, over the last 3 years, are shown in the accompanying figure. These results indicate that the North American plate appears to be extremely stable.

Shown also in the figure are measurements of the baseline between Haystack and Onsala, Sweden over the past 3 years. Although it is premature to draw definite conclusions at this point, there is an indication of lengthening of this baseline by about 2 cm/yr, which is consistent with the predictions of global plate tectonic models. If confirmed over the next year or two, this would mark the first direct measurement of continental drift between two major continents.

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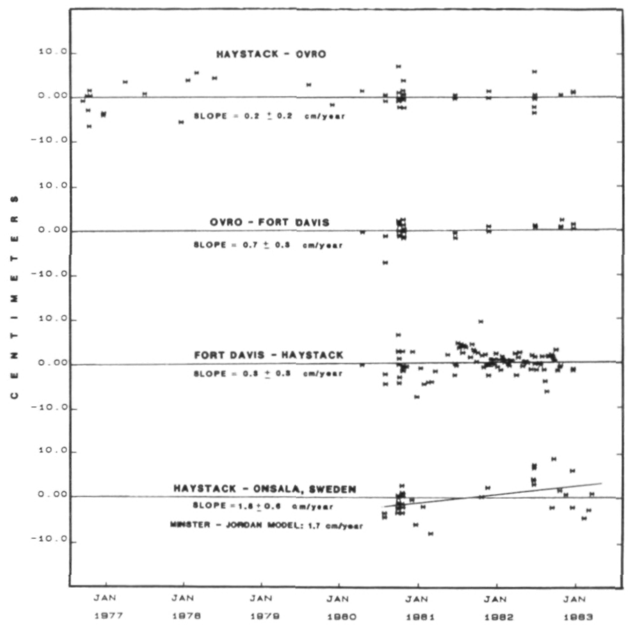

Baseline measurements over a 6-year period.

Earth Resources — Forestry, Land Resources, and Agriculture

Earth resources research efforts have addressed four general areas: (1) fundamental research into the dynamic properties and processes of vegetational physical systems and the interaction of vegetation systems with other physical systems such as hydrology, atmosphere, etc.; (2) development of models to

represent and revise understanding of vegetation physical systems; (3) the evaluation and use for research/applications of data from spaceborne sensors such as Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Advanced Very High Resolution Radiometer (AVHRR), from aircraft scanners which simulate recently launched or proposed space sensors, and sensors employing new technologies such as Multispectral Linear Arrays (MLA's); and (4) development of systems capable of processing and analyzing high spatial resolution data.

With the successful launch of the fourth Earth resources observation satellite, Landsat-4 in July, 1982, much work was directed towards documenting the characteristics and applications of the data. This satellite placed into orbit the first of the second-generation optical-mechanical scanners, the TM. Also on board is the fourth MSS, similar to three MSS previously flown. Quantitative studies were undertaken on a predominantly agricultural/forested area to determine the effects of the spectral, spatial, and radiometric differences between the two Landsat-4 sensors. The results of a rigorous statistical procedure indicated that the 30-meter spatial resolution of the TM data did not significantly alter land cover classification accuracy using a per-point classifier. The improved radiometric and spectral waveband characteristics of the TM data, however, did significantly improve classification performance. A similar study conducted over an urban/suburban test site confirmed these results. The lack of land cover classification improvement noted at the finer resolution may be a function of the classifier used (i.e., per-point) and indicates that 30-meter data merit the use of contextual or per-field classifiers.

A contextual classifier has been developed to facilitate analysis of high resolution image data from sensors such as the Landsat TM. The contextual approach differs from conventional, per-point classifiers in that the spectral and/or spatial properties of neighboring picture elements are considered in the classification process. Test results showed that classification accuracy in discriminating between five spectrally heterogeneous land use classes was improved by as much as 20 percent compared to per-pixel classifications using 7.5-meter data. TM and other high resolution data differ from coarser resolution data not only in terms of information extraction, but also in terms of the amount of data which must be processed for a given area. A histogram-based clustering procedure has been developed which uses significantly less cpu time than the per-point parametric classifiers for a large number of samples. In addition, this technique has been further developed to efficiently compute the number of distinct spectral vectors and their frequency of occurrence in Landsat-4 TM data. Continued software development will be necessary to handle the information extraction requirements and the increased data quantity inherent with the high resolution imagery.

A joint research project involving NASA/Goddard Space Flight Center and the Pennsylvania Bureau of Forestry has demonstrated the utility of Landsat data for assessing forest insect damage. A map-registered, MSS digital data base for Pennsylvania has been developed and implemented on Penn State University computers. A user friendly data management system has also been developed to provide an interface between the various layers of information within the data base and image analysis software. The data base, which contains multidate MSS imagery, a Landsat-derived forest resources map, and digitized forest district and county boundaries, is being used to monitor gypsy moth defoliation statewide.

Active remote sensing systems are being investigated to assess their utility for vegetation identification and condition recognition. A pulsed nitrogen laser, engineered to provide profiling (ranging) data, has been flown over defoliated forest canopy in Pennsylvania. Work there has shown that the data are sensitive to changes in the forest canopy density and tree heights. To accurately link these data with standing biomass estimates, the tree species being lased must be known. If tree species can be identified from aircraft laser data, then a remote sensing system capable of transect-sampling large forested areas quickly may be envisioned. AVHRR data have been extensively analyzed in a variety of vegetation monitoring studies. The data have been used to identify an area about 100 by 400 kilometers in Rondonia, Brazil where massive forest clearing or deforestation is occurring. The large size of the program and decreasing postclearing soil fertility in Rondonia indicate that the deforestation is occurring. The large

size of the program and decreasing postclearing soil fertility in Rondonia indicate that the deforestation will proceed more rapidly than has previously been documented in the Amazon Basin. NOAA-6 and -7 AVHRR data were used to study volcanic dust deposition from the El Chichon eruptions which began March 28, 1982, in southern Mexico. The data were used to determine the extent of the tephra falls in the areas adjacent to the volcano. Studies in Senegal have shown that a vegetation index which is related to green biomass may be calculated using the AVHRR red and near infrared channels. Analysis of nine AVHRR scenes acquired over a 3-month period showed that changes in this vegetation index were closely associated with precipitation events. This relationship between the AVHRR data and green biomass has been put to use in northern Africa and the Near East to monitor agricultural crops and rangeland resources. The synoptic coverage at the continental scale offers the only possibility for cost effectively monitoring the 16-million-square-kilometer desert locust recession area. The extent of the damage caused by the desert locust depends on the population dynamics of the insect which is turn are a function of the condition of the vegetation. AVHRR data may be used to detect the green vegetation blooms which are a precursor to the formation of devastating insect swarms containing billions of locusts. AVHRR data have been composited to produce cloud-free imagery for the continent of Africa. Data collected over a 3-week period are composited to remove clouds, thereby providing cloud-free imagery even for equatorial regions. These data have been used to monitor continental changes in the density and extent of green leaf vegetation over the course of a year. AVHRR research continues with the expectation that these data will be an integral part of future global habitability programs.

Agricultural remote sensing research efforts have documented changes in the bidirectional reflectance of crops as a function of leaf orientation distribution, canopy row orientation, illumination, and sensor position conditions. The effects of off-nadir viewing have been described and explained in terms of the structure of the vegetation canopy sensed using ground-based spectral measurements. The work has been done in response to 1) the possibility that future sensors may be pointable (i.e., capable of obtaining data off-nadir) and 2) that some operational space sensors obtain data at large off-nadir scan angles.

Hand-held radiometers have been used to measure the directional reflectance characteristics of agricultural canopies. The dynamics of directional reflectance have been interpreted relative to changing spectral band, geometric structure of the scene (including leaf heliotropism), solar zenith and azimuth angles, and the optical properties of leaves and soils. For complete homogeneous vegetation canopies, the major trend observed at all Sun angles and spectral bands was a minimum reflectance near nadir and increasing reflectance with increasing off-nadir view angle for all azimuth directions. This trend is caused by the shading of lower canopy layers by the upper canopy layers and by viewing different proportions of the overstory and understory as sensor view angle changes. Sparse canopies behaved quite differently due to the anisotropic scattering properties of soils.

These findings and similar data collection methods have been used to define the optimal directional view angles for remote sensing missions. Data were collected in red and near infrared bands at various solar zenith angles and analyzed to define the optimal directional viewing angles with respect to two strategies. The first strategy defines the optimum viewing angles for minimizing spectral reflectance differences between nadir and off-nadir response. Results showed that the optimum view angles are in the direction perpendicular to the target/Sun plane for all targets, bands, and Sun angles. The second strategy defines those view angles which provide superior and/or additional information about the physical characteristics of the targets relative to the nadir response. Results showed that the optimal viewing angles were parallel with the target/Sun plane. These results provide valuable information for interpreting remotely sensed off-nadir data and will aid in the development and design of future systems with off-nadir capabilities.

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Geophysics, Geobotany and Geology

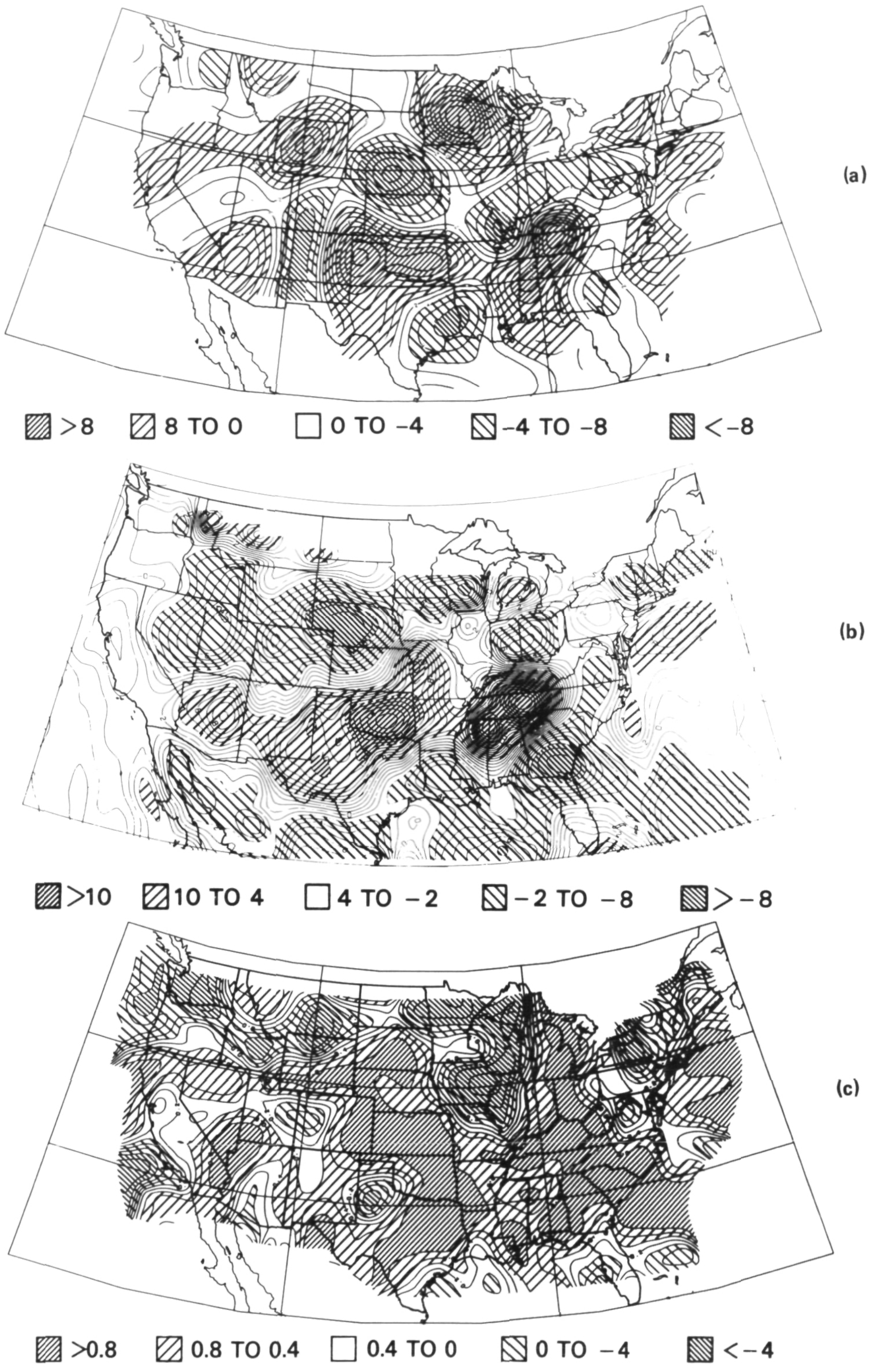
A systematic study of Magsat anomalies with amplitudes $\geqslant 2$ nT between ±80° latitude revealed a higher percentage of anomalies over the continents than over the oceans. Continental and continental shelf anomalies make up 56 percent of the more than 300 features identified, even though these areas comprise only about 40 percent of the Earth's surface. Within the continents the anomalies are distributed roughly as are tectonic provinces: most anomalies lie over platforms or orogenic zones. More than 25 percent of the oceanic anomalies lie over submarine plateaus, which has led to detailed modeling studies of these features. Several major subduction zones have positive Magsat anomalies near them, and in preliminary reduced to pole POGO data the centers of these anomalies are situated over the overriding plate. Modeling studies have shown it is the subducted slab which produces the satellite-elevation magnetic anomaly, because the slab remains cold and relatively magnetic with respect to the surrounding hotter mantle. The amplitude of the anomaly depends not only on the susceptibility contrast and volume (thickness, length, width) of the slab but also on its dip angle. The same slab produces a stronger anomaly if it has a more shallow dip during subduction, and the center of the anomaly becomes displaced further from the trench. Satellite magnetic anomalies over submarine plateaus are mostly positive, especially in the POGO reduced-to-pole data. Because two extreme models exist for submarine plateaus (thickened oceanic crust or submerged continental crust), models for a wide variety of such structures were generated. Thickened oceanic crustal plateaus produce positive anomalies, as expected, whose amplitude generally increases with plateau thickness. Plateaus formed from submerged normal continental crust generally produce negative anomalies or very weak positive anomalies (in a vertical field) due to their relatively negative susceptibility contrast with respect to the surrounding oceanic crust. This work suggests that satellite-elevation magnetic anomalies may be useful in understanding the origin and nature of some of the less well known submarine plateaus.

In order to evaluate further the validity of the Magsat crustal anomaly map, a quantitative comparison was made between these satellite-derived measurements and the recently released U.S. Geological Survey/Society of Exploration Geophyicists Composite Magnetic Anomaly Map (CMAM) of the U.S. Agreement was found between many of the large amplitude magnetic anomalies (such as those off the east coast of the U.S., in Kentucky, Oklahoma, Georgia, Arizona, Nebraska, and the Mississippi Embayment); however, disagreements occurred over the Rio Grande rift, Minnesota and Wyoming. Disparities between these data sets reflect: (a) imprecise long-wavelength core field removed from the satellite measurements and; (b) inexact zero-reflectance level subtracted from the CMAM (for example, Minnesota and Wyoming). With the global coverage provided by satellite-derived fields, we can link these smaller aeromagnetic surveys, used in the CMAM, both in a continental and eventually a global scale.

Magnetic anomalies are the result of contrasting magnetization in the Earth's crust. This magnetization has two components, induced—caused by the Earth's present magnetic field—and remanent—produced by an older Earth's field and "frozen" into the crust. It has been previously suggested that it is not possible to derive any remanent or "fossil magnetization" from satellite magnetic anomaly data, not even if this remanence is a significant part of the anomaly. Recent studies of the Kursk anomaly in the Soviet Union, however, demonstrate that it is possible to model this feature, using two simple rectangular blocks, and to derive a remanent vector of magnetization. While this study is in a preliminary phase, it does indicate that we should be able to estimate the fossil magnetism of large crustal anomalies from the satellite data, even though the modeled solution is not unique.

An alternative model has been proposed to high heat flow in the region of the New Madrid Fault Zone of the Mississippi Embayment as the cause of the regional satellite magnetic low in the area. The model requires the emplacement of igneous rock at depth under conditions of low oxygen fugacity. The intrusion thus formed could have a low Curie temperature, approaching 200°C, and a low magnetization even if the heat flow is normal.

In FY83 a 3-year field study on the relationship between vegetation spectra and the concentration of



Comparison between the Composite Magnetic Anomaly Map (CMAM) of the U.S., compiled from hundreds of local and regional aeromagnetic surveys, and the Magsat measured anomaly field. (a) The CMAM, analytically continued upward to satellite altitude. Contour interval is 2 nanoteslas. (b) Magsat determined anomaly map at same altitude. Contour interval is 1 nanotesla. (c) Correlation between the two maps.

mineralization in the underlying soil was successfully tied together. In the 1982 field season a "blind" experiment was conducted at a site near Arvonia, Virginia. In this work leaf reflectances were collected and analyzed from trees on a 420-point grid covering an area of 1.2 km by 0.5 km. The only prior knowledge available was: (1) the presence of a soil anomaly somewhere in the area, and (2) previous results which suggested that variation in leaf reflectance related to mineralization was most evident in the early fall just prior to senescence. Using only reflectance information from hand-held radiometers set up to mimic Thematic Mapper (TM) band 3 (0.63-0.69 μm), band 4 (0.76-0.90 μm) and band 5 (1.55-1.75 μm) and some relatively simple data analysis techniques, six areas representing approximately 20 percent of the test site were identified. One of the six areas persisted throughout the entire analysis procedure and was selected as the most promising candidate. When the soil geochemistry was made available by the cooperating mineral exploration company, it was found that the selected area lay directly on the location of maximum copper mineralization.

The HCMM Anthology, a 256-page NASA Special Publication that summarizes research results from the 1978 Heat Capacity Mapping Mission, was completed with publication expected in October 1983. Imagery and other materials for preparation of *Regional Landforms from Space* were procured from numerous sources. This book, planned as a NASA SP, will help establish a scientific foundation for quantitative geomorphic analysis of large areas viewed synoptically from various satellites and manned platforms. Publication is scheduled for 1984.

A detailed study has been made of the northern Death Valley, California, region as imaged by the Landsat-4 TM. Using digital data, supervised classifications were made of mappable rock units. Accuracies of 50 to 79 percent were achieved for identifying these units relative to the 1977 geologic map dependent upon classification techniques. This is not significantly better than determined previously for comparable geologic settings using Landsat MSS data. This suggests that accuracy is controlled more by inherent natural limitations in the ground track than by sensor performance.

Further study of the distribution of small martian volcanic cones has included investigation of morphological subclasses of the cones and their relation to background terrain. Although different morphological classes can be identified, the cones are dominantly of one type and the different classes seem to represent natural variation within a sample. The cones have been found on six different types of plains-forming units in the Acidalia Planitia region of Mars, and some differences with terrain do exist. Cones on fractured plains are less abundant, more thinly distributed and generally larger than those on smoother plains. Differences in the crater/cone diameter ratio are noted among the smooth plains cones: those on the youngest, smoothest plains include more examples with lower crater/cone ratios than the volcanoes on older, more mottled plains. Many of these differences may be due to erosion of the cones over time, or, perhaps, to aeolian deposition on the plains. A recently completed Ph.D. study of morphometric parameters of terrestrial and martian channels thought to be fluvial in origin revealed that while satellite imagery is satisfactory for morphometric analysis of fluvial systems, most parameters measured cannot by themselves demonstrate a uniquely fluvial origin for terrestrial channel systems. While the channel-like features on Mars may well be due to fluvial processes, this type of analysis cannot prove the hypothesis. This casts doubt on previous results published by other investigators who, in general, have studied fewer parameters and who have argued on the basis of less information that the martian systems are similar to those on the Earth.

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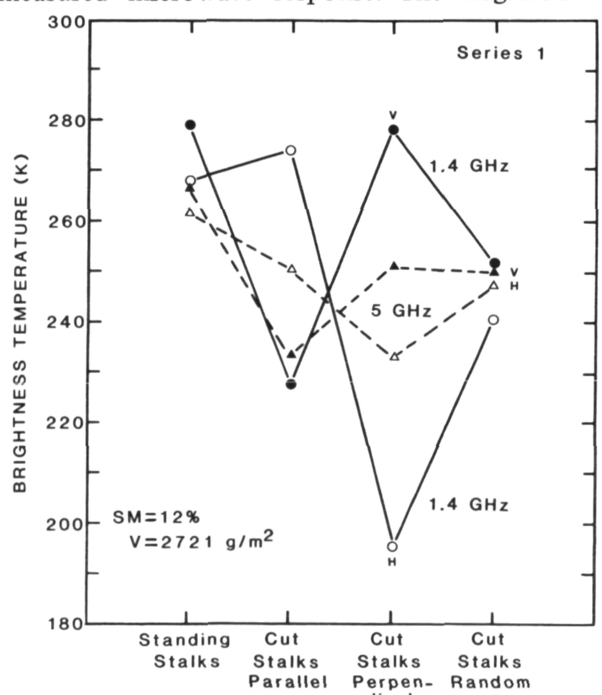
Hydrology

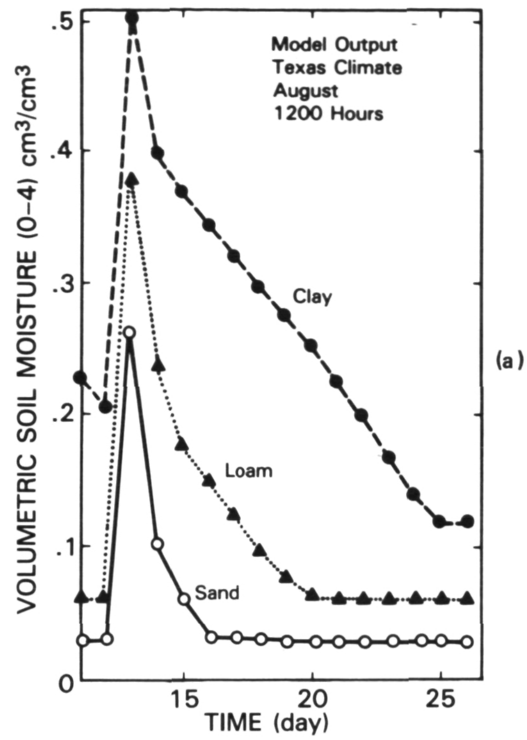
The thrust of research in hydrology is to develop techniques for using remote sensing to monitor hydrologically important variables and processes. Thus, ongoing projects focus on determining soil moisture, estimating evapotranspiration, studying

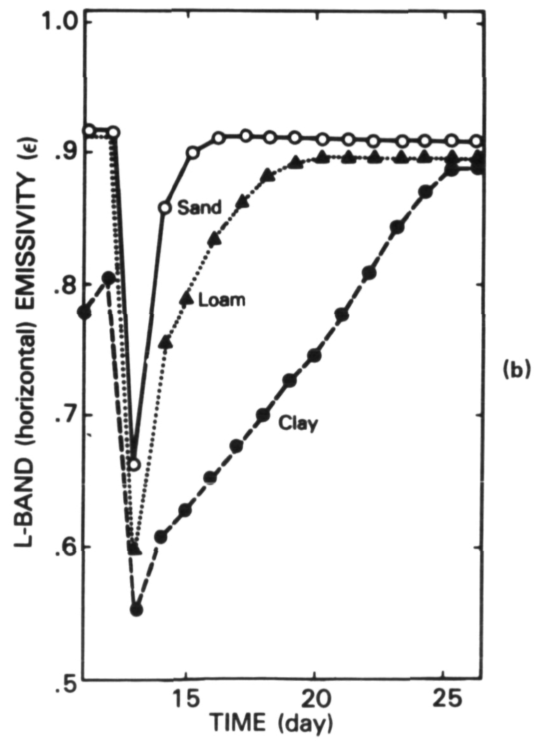
energy interactions within vegetation canopies, measuring snowpack properties, and characterizing watersheds and flood plains. These projects blend field work with theoretical and numerical modeling to identify and understand the electromagnetic signature of the hydrological variables and processes at all wavelengths practical for satellite remote sensing—microwave, thermal infrared, near infrared, and visible. Much work emphasizes microwave sensors, because they are useful in all weather conditions, which is a distinct advantage for hydrological applications.

In order to extract soil moisture information from remotely sensed observations of a vegetation-soil complex, the effects of vegetation on the microwave response must be well understood. During the summer of 1982, NASA and USDA conducted a series of vegetation experiments with GSFC's truck-mounted microwave radiometers which indicate that certain crops (such as mature corn) have both biomass and structure properties which influence the microwave sensitivity to soil moisture. In particular, the orientation of stalks and the presence of vertical structure in the crop canopy can greatly affect the measured microwave response. The magnitude of



Effect of corn stalk orientation on measured brightness temperature with vegetation biomass held constant. SM is volumetric soil moisture in the 0 to 5 cm layer; V is vegetation water content.





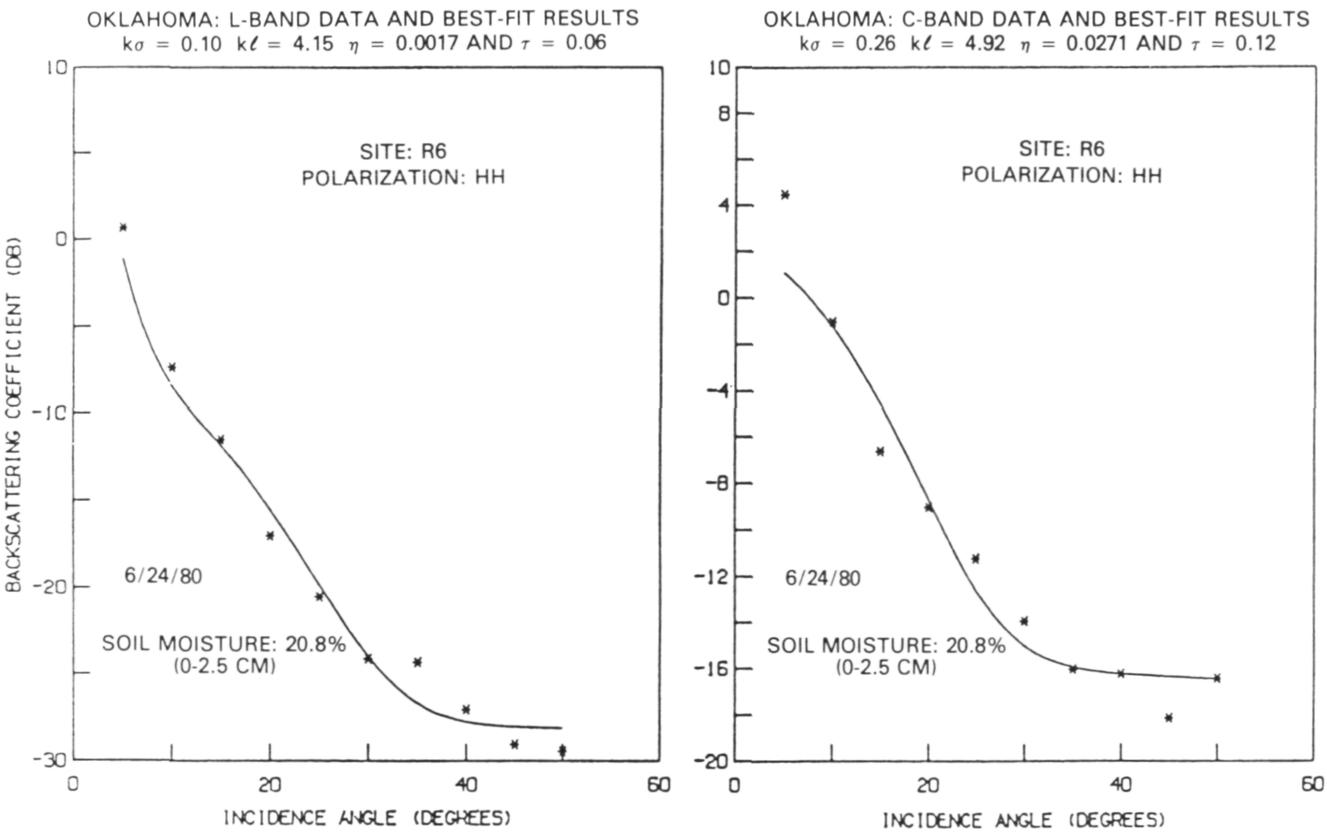
Time series microwave emissivity values expected from three different soils during a simulated soil moisture dry down. Soil moisture profile data from a soil physics model (a) were used as input to a radiative transfer model (b).

this effect varies with the amount of water in the plant, disappearing at low levels of vegetation water content.

Analysis of model simulations and microwave data obtained from truck-mounted radiometers has verified the concept of using time series microwave measurements to distinguish between soil type based on their hydraulic properties (such as ponded infiltration rates, water holding capacities, etc.). Results indicate that a relative classification of the hydrologic soil type can be accomplished with a one-time microwave measurement if it is known that the surface soils were subjected to significant rainfall from ½ to 2 days prior to measurement. A more quantitative classification can be made if a long-term time series of microwave data can be collected over large areas where some ground verification of soil properties is available.

A comparison of the soil moisture response of three 1.4-GHz radiometers from truck and aircraft platforms at a variety of test sites indicates that microwave remote sensing of bare soil produces repeatable and quantifiable results regardless of geographic location and sensor system used. The combined microwave sensitivity of these data sets appears to be on the order of 2.7 K per 1 percent change in volumetric soil moisture for the L-band wavelengths (3.4 K/percent soil moisture if watersheds characterized by vegetation and surface roughness are eliminated). Detailed examination of data from aircraft flights over agricultural fields in South Dakota suggests that when the data are partitioned according to the level of roughness, a direct relationship can be found between the degree of roughness and the microwave response. With the addition of appropriate algorithms to handle the effects of roughness and vegetation, all of these results demonstrate the potential of microwave remote sensing for estimating soil moisture over large areas.

In related modeling research, GSFC investigators have developed an electromagnetic wave scattering model to simulate the measured angular distribution of radar backscatter from vegetation-covered soil surfaces using a least-squares fit method. The model

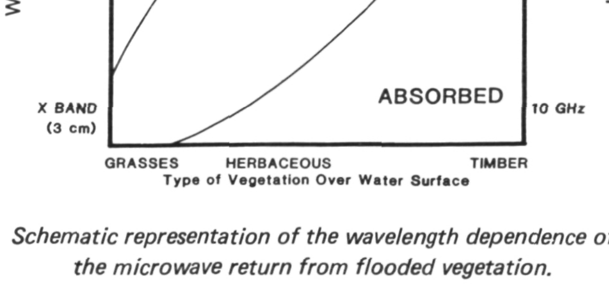


Comparison of model calculations (solid curves) and scatterometer data (asterisks) for a grassland watershed in Oklahoma.

takes into consideration coherent and incoherent scattering from a rough soil surface, which is characterized by two parameters, the surface height standard deviation and the surface correlation length. The effects of vegetation canopy scattering and attenuation are also included in the model. The model results agree well with data obtained at both L-band (1.6 GHz) and C-band (4.75 GHz) frequencies. Inversion of model fits to a large collection of scatterometer data can provide reliable estimates of the surface roughness characteristics, particularly the standard deviation of surface height variations.

In another vegetation study, five different sets of radar data (X, C and L-band) taken over similar vegetation were used to study vegetation discrimination in wetland and flooded areas. Analysis indicates that the amount of microwave backscatter is dependent on the height of the vegetation, the radar wavelength, and the presence or absence of standing water beneath the vegetation canopy. The longer 21-cm wavelength (L-band) radar displays a brighter return in regions of flooded timber, while the shorter wavelength X-band radar shows an increased response in areas where the vegetation is predominantly short grasses or shrubs. From this information it appears that determination of the extent of flooding under vegetation, as well as vegetation delineation, can be improved through the use of multispectral radar and visible and near infrared data.

Theoretical modeling can help to improve our understanding of the fundamental physical processes at work within a vegetation-soil complex. Canopy



Schematic representation of the wavelength dependence of the microwave return from flooded vegetation.

temperature represents the integrated response of a crop to prevailing weather and soil water conditions. If changes in canopy temperature due to weather can be quantified and accounted for, then it should be possible to infer the soil water status from the canopy temperature. A steady-state model of transpiration has been developed which solves the water balance equation for a plant by explicit accounting of plant physiologic control of water loss from leaf stomata. Knowing transpiration, the canopy temperature is obtained from the energy balance equation. For well-watered corn, soybean and sunflower crops, the canopy temperature during the significant portion of the daylight period is determined largely by air and dewpoint temperatures; wind speed and solar radiation have very little effect on the canopy temperature. As root-zone soil water decreases, the canopy temperature increases; this increase is predictable in terms of crop physiology and soil water potential.

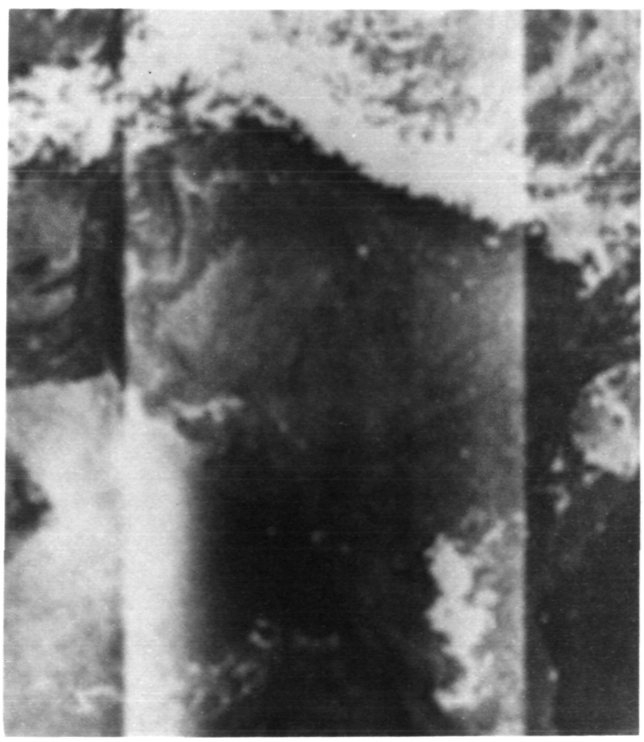
A model of the energy and moisture fluxes in the soil and atmospheric boundary layer has been applied successfully to estimate daily evaporation over wheat and barley fields in Germany using thermal infrared remotely sensed data. A sensitivity analysis of the model showed that for bare soil net radiation was the most important independent variable required, while for wheat and barley the air temperature and vapor pressure were as important as the net radiation. Thus, ground data requirements do not appear to be excessive when used with remotely sensed data to calculate evaporation with the physically based model. Overall, surface temperature was the most critical remotely sensed parameter, although soil moisture could be an important model input under nonpotential evaporation conditions.

Snow parameters are of special interest to the disciplines of hydrology and climatology, and efforts are continuing to use these parameters in predictive models. One such model utilizes remotely sensed snow covered area, daily temperatures and a degree-day factor to estimate snowmelt runoff, and has proven to be more accurate for short-term forecasts (1 to 2 days) than conventional runofff models using the Kings River basin in California as a test watershed. During FY83, this model was also converted to a predictive mode, and a 6-month hydrograph produced for the South Fork of the Rio

Grande River compared well with the actual measured flow.

The extent of snow covered area is an important variable which cannot be monitored on cloudy days by satellite sensors operating at visible wavelengths. The feasibility of observing snow cover at night by moonlight was demonstrated using data from the Defense Meteorological Satellite Program (DMSP) whenever the Moon was sufficiently bright to illuminate a snowpack on the ground (between its first and last quarter phases). Night observations of this type could add five additional viewing opportunities a month to daytime observations of snow cover, and thus could contribute significantly to timely mapping of snow throughout the snowmelt season. Since Landsat satellites cannot take visible images at night because their sensors are not as light-sensitive as those of the DMSP, improved light sensitivity of such instruments should be an important consideration in future satellite design.

Passive microwave data can also be used to overcome the limitations of satellite observations of snow in visible wavelengths because of the ability of



Nighttime image of snow extent in the Himalayan mountain range north of the Indian subcontinent. The image was taken by the broad-band visible sensor on DMSP on March 16, 1978 when the Moon was in first quarter phase.

microwave sensors to acquire data in nearly all-weather, day/night conditions. Nimbus-7 SMMR data were compared to NOAA AVHRR data for studying snow-covered areas in the Northern Hemisphere. The SMMR-derived snow maps agreed well with the weekly NOAA snow and ice maps over large homogeneous areas. Although snowpack melting and heavy forest cover seems to affect the accuracy of microwave mapping of snow cover at this time, additional research in these areas is currently being pursued using multifrequency data to account for the effects of vegetation.

In other snow research, SMMR data were also used to investigate the condition of the snowpack in three midwestern states. In this study, vertically polarized data did not correlate well with the horizontally polarized measurements. Although the precise reason for this phenomenon is unknown, it is speculated that metamorphism in the internal and/or surface conditions of the snowpack may cause the vertically polarized data to be unresponsive to the snowpack. Modeling is now underway in an attempt to prove or disprove this hypothesis.

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Oceans and Ice Research

The Oceans and Ice Branch conducts theoretical and numerical work in various areas of oceanic and cryospheric dynamics. Some of the studies deal with upper ocean physics and ocean heat transport problems. Using these studies, the impact of improved remote sensing techniques on the determination of prediction of the ocean state can be estimated. More importantly, the use of better descriptions of the mechanisms and physics of the ocean response leads to increased effectiveness of the remote measurements.

One example of such improved prediction arose from the unusual behavior of the tropical Pacific Ocean during 1982, when a large sea surface temperature (SST) anomaly evolved in a rather surprising fashion. Previous theories for equatorial Pacific

warming (the El Nino) have correlated the SST anomalies to the surface height anomalies, driven by wind changes in the basin. Correct upper ocean thermodynamics reveals, however, that the SST change mechanism is advective, and therefore the currents and mean thermal gradient are the essential variables for SST prediction. Application of wind measurements to such an advective model predicts both the normal El Nino evolution and the uncommon 1982 event–a combined prediction which the surface height theory fails to make.

The ocean color program is focused on the physical and biological processes in the South Atlantic Bight, the region between Cape Canaveral and Cape Hatteras. A data base of roughly 70 Coastal Zone Color Scanner (CZCS) scenes over a 1-year period has been collected to study the seasonal variability of the shelf processes. A large effort has gone into developing an interactive CZCS processing capability on the Atmospheric and Oceanic Image Processing System (AOIPS) facility, and the CZCS imagery can now be remapped into a Mercator projection for analysis using the Nimbus Experiment Team (NET) algorithms. Studies are also underway to make an intercomparison of the atmospheric correction techniques on the CZCS and U-2/Ocean Color Scanner data. In addition, efforts are underway to carry out a systematic intercomparison between field data collected in the Gulf of Mexico and the Middle Atlantic Bight (MAB) and the data from Advanced Very High Resolution Radiometer (AVHRR-II) on the NOAA satellite during 1982. The comparisons of the sea surface temperatures showed varying results. The best results were obtained for the MAB data set during the winter of 1982. The two data sets for April and September of 1982 from the Gulf of Mexico indicate the pronounced effect produced by El Chichon with biases in the SST up to 2.3C. Analysis of CZCS data collected during this period is also underway.

The key to the study of the ocean by remote sensing techniques from satellites is the understanding of the microscale ocean surface dynamics. More specifically, we need the statistical properties of the ocean surface. During this year we have:

(1) Established a theoretical model for non-Gaussian slope-height joint distribution and observed the probability distribution under a wide range of wind speeds and background wave conditions. As the wave field became more nonlinear, the joint probability density function became more non-Gaussian. We found this deviation to be characterized by a single parameter, the significant slope (defined as the mean square wave elevation divided by the dominant wavelength). Based on this, the closed-form theoretical expression was compared with observations. The agreements were remarkably good.

(2) Extended the Wallops spectrum model into shallow water. Almost all engineering activities in the ocean are confined to the shelf break and inward where the bottom effect will be felt by the long energy-containing, damage-causing waves. The advantage of the Wallops spectrum model in correctly modeling the energy-containing range of the spectrum in deep water is now extended to water of any depth, with the additional controlling parameters of nondimensional depth, and the Ursell number. This extended model gives a variable spectral slope depending on the wave and depth conditions and provides a closed-form expression for the whole spectrum.

The Goddard Short Pulse Radar Ocean Wave Spectrometer (ROWS) program is concerned with developing a viable satellite remote sensing technique for global measurements of ocean wave directional spectra (the distribution of wave energy in wavelength and direction). Considerable progress toward this end has been made in the past several years. We have shown theoretically and experimentally that these global measurements can be made simply and economically using existing short pulse satellite altimeters (such as the Seasat altimeter) modified so as to include an off nadir (*ca*. 10 degrees incidence) conical scan mode in addition to the nadir altimeter mode. Further, we have shown that these measurements can be made with great fidelity over a large number of environmental conditions, and that absolute energy levels can be inferred with great accuracy (*ca*. 20 cm rms in terms of significant wave height over a 7-m range of wave height). The current program emphasis is now: 1) defining a Space Shuttle experiment to demonstrate the ROWS technique in space, 2) obtaining additional verification/intercomparison data with the Wallops Surface Contour Radar (SCR), a direct

topographic mapping radar having comparable directional resolution to the ROWS, and 3) conducting basic scientific investigations of ocean waves using the ROWS (and SCR) as the principal measurement the performance of numerical wave models using Fall '78 Mission synoptic ROWS observations of storm sea conditions in the Norwegian sea. The intercomparison shows that while the hindcast may reproduce integrated properties of the spectrum (such as wave height), the model can be in great error in describing the directional distributions. This is due to both errors in the specifications of the wind field and in the model's parameterization of directional relaxation. The January 1983 Mesoscale Air-Sea Exchange (MASEX) fetch-limited wave growth data set already is yielding new scientific knowledge, and should prove to be a rich source of basic wave information for some time in the future. For example, our preliminary analysis indicates faster-than-linear wave growth (in contradiction to the JONSWAP results); the profound influence of coastline irregularities on the wave field; and weak directional coupling (e.g., no observed turning of off-wind components into the wind direction).

A definitive long-term decrease in the extent of antarctic sea ice is not detectable from 9 years (1973 to 1981) of year-round satellite observations and limited prior data. Regional interannual variability is large, with sea ice decreasing in some regions while increasing in others. A significant decrease in overall ice extent during the mid-1970's, previously suggested to reflect warming induced by carbon dioxide, has not been maintained. In particular, the extent of ice in the Weddell Sea region has rebounded after a large decrease concurrent with a major oceanographic anomaly, the Weddell polynya. Over the 9 years, the trends are nearly the same in all seasons, but for periods of 3 to 5 years, greater winter ice maxima are associated with lesser summer ice minima. The decrease of the mid-1970's was preceded by an increase in ice extent from 1966 to 1972, further indicating the presence of cyclical components of variation that obscure any long-term trends that might be caused by a warming induced by carbon dioxide.

Multichannel cluster analysis using effective emissivities derived from the dual polarization Scanning Multichannel Microwave Radiometer (SMMR) and the Temperature Humidity Infrared Radiometer (THIR), both from the Nimbus-7 satellite, showed new insights on how to handle various problems associated with the remote sensing of sea ice. Various surface and subsurface characteristics such as wetness, snow cover, and salinity cause considerable variability in the emissivity of ice especially at the higher frequencies. The use of an iterative procedure, using two channels at different frequencies has been shown to be effective in improving the accuracy of ice parameters extracted from the SMMR data.

A field study of the Bering Sea Marginal Ice Zone (MIZEX), involving American, British, and Canadian scientists was conducted from February 5 through 27, 1983. This experiment, known as MIZEX-West was part of a comprehensive study of air-sea-ice interactions operative in the marginal ice zones of the Northern Hemisphere. The field operations included data collection by two ships, two instrumented aircraft, and three satellites. A major portion of the remote sensing program centered on a series of seven overflights by NASA's Convair 990 airborne laboratory which were coordinated with the NOAA WP-3D research aircraft, the Nimbus-7 spacecraft, and surface radiometeric measurements of sea ice. The purpose of these flights was to improve the ability to determine sea ice characteristics from passive microwave satellite observations and to provide an overview of the Bering Sea marginal ice zone morphology for process studies. The NASA aircraft was equipped with several passive microwave radiometers, an infrared radiometer, two cartographic cameras, and a version of the radar altimeter planned for the European Space Agency satellite ERS-1. Sea ice concentration and type are determined from the microwave radiance data, ice surface roughness and directional ocean swell spectra from the radar returns, and ocean and ice surface temperature from the infrared radiances. Visual and photographic records of the general ice characteristics also made during the flights will provide supporting data for interpreting the microwave measurements.

Near real-time sea ice concentration data obtained from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) were provided in support of MIZEX/West through the auspices of Canadian

Atmospheric Environment Service, which obtained the data through the oceans network system of U.S. Navy Fleet Numerical Oceanography Center. The benefits of this service were great enough to warrant the development of our own capability for providing near real-time SMMR sea ice concentration for the MIZEX/East '83 experiment in the Fram Strait/East Greenland Sea, which took place from June 15 through July 31, 1983.

The effort resulted in significant improvements in the accuracy of predicted Earth locations and sea ice concentrations as well as in spatial resolution, display format, and turnaround time for data processing. The sea ice concentrations were transmitted for each SMMR operating day (every other day) on a standard polar sterographic projection with 15-km pixels using ASCII character codes via electronic mail (OMNET) within 6 hours of data receipt to the Norwegian Satellite Telemetry Station at Tromso, which was the control center for the MIZEX/East '83 field expedition. This provided a valuable service in helping to determine the placement of the sea ice/ocean data buoys, the floating ice station, and the aircraft surveys.

Two studies are underway to examine the effect of the West Antarctic on global habitability. A rapid rise in the sea level caused by the increased discharge of fast-moving ice streams is possible if the atmospheric and oceanic temperatures increase. The magnitude of this phenomenon over the next few hundred years is being examined using the predictions of a warmer climate containing twice the current amount of carbon dioxide from an atmospheric general circulation model developed at the Goddard Institute for Space Studies. In addition, glaciologists from the branch will be involved in the 1983-84 Antarctic field mission, measuring the motion and temperature of some major Antarctic ice streams. The goals are to use the data received to assess the current behavior of this region of the Antarctic, to deduce what the past behavior had been, and to understand the dynamic processes better to improve model predictions of the future behavior of Antarctica.

Initial results of the Nimbus-7 CZCS showed that multifrequency visual observations of the ocean can yield maps of chlorophyll concentration as well as indications of turbidity and organic matter. A science working group defined the data needs for biological as well as physical oceanographic studies using this technique. A technical feasibility study has been conducted to define an ocean color instrument to fly on one of the NOAA satellites and a new start proposal has been submitted to NASA Headquarters. Another study evaluated the performance of the Argos system, which is currently locating and relaying data from ocean instrument platforms, to determine its adequacy for future data collection requirements. The study examined ways of making the current system more efficient and also designing a higher capacity system. A demonstration program was started in collaboration with the Woods Hole Oceanographic Institution.

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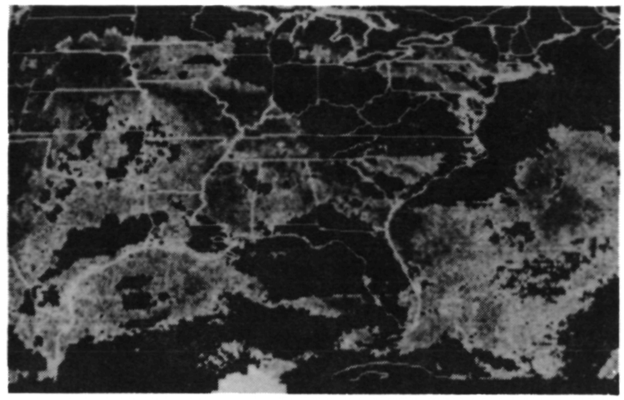
TECHNOLOGY

Technology programs at GSFC are directed toward providing advanced technology for the development of new sensors, for spacecraft subsystems, and for the extraction of information from the data obtained in space missions. Efficient and reliable tracking, communications, and data acquisition are essential for NASA flight operations if they are to meet their mission objectives. GSFC is pursuing several programs to develop new techniques for the tracking, acquisition, and handling of data from future flight programs.



SPACE TECHNOLOGY

Advanced Power System Technology

The Goddard Space Flight Center has had a program in Advanced Power System Technology since 1980. The objective of this program is to bridge the gap between research accomplishments and flight applications of new power system or power system component technologies, thus reducing the risk to the science and application missions of implementing the new technology on the spacecraft bus. As a result, the program encompasses a diverse variety of elements.

Technology Assessment

Both future technology needs and new technology accomplishments are assessed by analyses of current planning documents and power research reports and through participation in program planning, workshops, agency and interagency power working groups, etc.

The Goddard Space Flight Center Battery Workshop, which has been held annually since 1968, is one typical element of this assessment process. The workshop provides a forum for exchange of up-to-date information on electrochemical cell and battery technology. The workshop itself leads both to a more fully informed user and to definition of further developments needed prior to implementation of the new battery technology on flight projects. Hopefully, the end result would be improved cells and batteries for both aerospace and commercial use. The proceedings of the workshop are published in the form of a NASA Conference Publication.

The most recent workshop was held November 16-18, 1982, and was attended by more than 200 persons, including government, nongovernment, and foreign participants. The program format included papers and discussions on the following subjects:

- New high energy lithium cell technology
- Cell modeling
- Charge control methodology
- Reconditioning as a viable technique
- Advantages and disadvantages of nickel-hydrogen cells

The format for the next workshop, to be held November 15-17, 1983, has not yet been finalized.

Analytical Modeling

Spacecraft power requirements have been continually increasing over the years. Simultaneously, flight instruments have become increasingly sophisticated and more sensitive to noise on the spacecraft power bus. The former makes testing of the integrated power subsystem more and more difficult, if not impossible, because of the large size and fragility of the solar arrays, and the latter makes it necessary that detailed subsystem ac characteristics be known, even for such dc components as the solar arrays and the batteries. To solve these problems, an effort is underway to develop an accurate analytical ac/dc model for spacecraft power subsystems. A study of requirements for such a model led to a concept which includes four model program types operated under an executive driver program. The four models are sizing and synthesis dc, small signal ac, and large signal transient models. The continuing effort emphasizes battery modeling, which was found to be a critically inadequate area, and small signal ac modeling, because of its importance to the stability of the spacecraft power bus.

The small signal ac approach uses a two-port component model and a two-port calculus consisting of manipulation of the matrices formulated from governing equations for the internal circuitry. Models have been developed and proven successful, while relatively easy to use, for several power subsystem components, including buck and boost regulators, shunt regulators, and filters.

Nickel-Hydrogen Cell Assessment

Future needs in energy storage for both manned and unmanned aerospace applications continue to emphasize improved performance, higher reliability and longer cycle lifetime. For electrochemical energy storage, the nickel-hydrogen system, a relatively recent addition to the family of alkaline electrolyte storage batteries, shows promise for substantial performance improvements over the conventional nickel-cadmium system. In addition, the nickel-hydrogen system has demonstrated an inherent insensitivity to overcharge and overcharge operational modes.

The basic electrochemical system consists of a catalytic gas negative electrode coupled with the nickel-positive electrode borrowed from the nickel-cadmium system. Electrochemically, the reactions at the positive electrode are the same as those occurring in the parent system. At the negative electrode, hydrogen is displaced from water by electrolysis during charge; during the discharge cycle, hydrogen is consumed by oxidation reaction at the negative electrode, producing electrical power.

Until recently, the primary concentration of interest was in nickel-hydrogen batteries for geosynchronous orbit applications and, since 1977, nickel-hydrogen batteries have replaced nickel-cadmium batteries in several satellites in either geosynchronous or highly elliptical orbits. However, these batteries experience only several hundred charge-discharge cycles during the spacecraft lifetime because of the limited number of eclipse seasons in these orbits. In comparison, batteries for low Earth orbit applications experience in excess of 5000 cycles in a single year.

The objective of the Goddard Space Flight Center nickel-hydrogen program is to develop an engineering data base for use by power system designers specifically for the low Earth orbit application. The program stresses parametric testing to determine cell characteristics and performance as a function of operating parameters such as charge rate, discharge rate and operating temperature. These tests include measurements of high and low rate capacity, coulometric efficiency, voltage charge control, self-discharge, and ac impedance. The evaluation also includes determining long-term life cycle performance under a simulated low Earth orbit cycling regime. Analysis of failed cells is performed to provide information on degradation and failure modes. The program will also provide a direct comparison of relative performance of nickel-hydrogen and nickel-cadmium cells.

Nickel-hydrogen cells obtained up to the present time have been found unsuitable for use. Failure analyses have been performed and the cells are presently undergoing redesign and rebuild. Evaluation of replacement cells, designed for the low Earth orbit application, will be performed.

Flywheel Energy Storage Assessment

A study, assessing the feasibility of utilizing superflywheels as mechanical energy storage elements in a

spacecraft power subsystem, has been completed, showing a potential for improved energy density and cycle life over conventional electrochemical energy storage systems. The study, based on benefits derived from the program in composite materials as applied to flywheel technology sponsored by the Department of Energy, resulted in a conceptual baseline flywheel system design. In this concept, the energy storage element consists of 2 high energy density wheels spinning in opposite directions to effectively cancel the large angular momentum of each single spinning wheel. The wheels, which spin at 30,000 revolutions per minute when fully "charged," are suspended using magnetic bearing principles and are accelerated/decelerated by a built-in high efficiency motor/generator similar to an automobile alternator. The rotating portions of the bearing, motor/generator and composite rotor are all contained within the rotating toroid (doughnut) shaped assembly. The remaining portions of the bearing and motor/generator are housed in the stationary "hole" of the spinning toroid. In this configuration, no axle, as found in most rotating equipment, is used. The benefits of this flywheel system, as applied in a power system for a satellite, compared to conventional electrochemical storage systems, are projected to be higher energy density, significantly longer lifetime (because there are no wear mechanisms in the magnetic bearing or motor/generator), simplified detection and control of the stored energy, and simplified implementation of voltage, particularly in high voltage power subsystems.

High Voltage Insulation Performance

Thorough nondestructive testing of electrical insulation in high voltage instruments and high voltage electronic assemblies for space use is of utmost importance to avoid catastrophic failures. For this reason, a partial discharge (PD) measurement facility is being established and developed at the Goddard Space Flight Center. The facility is capable of 60 kilovolts dc, and is being modified for added capability of up to 40 kilovolts ac or ac superimposed on dc, with capability of testing while the sample is in vacuum.

Because most spaceborne high voltage applications see dc in service, research so far has been mostly with dc applied voltage. A variety of potting resin samples, commercial capacitors, cables, and also high voltage assemblies, such as the faint object camera (FOC) tube of the Space Telescope, have been tested using a PD ramp technique where the voltage is raised linearly (ramp) in steps (quiescent plateau) to the final desired level. Characteristic or typical dc PD histograms of a wide variety of insulation configurations, both perfect and also purposefully flawed (controlled flaws), are now available. Acceptance/rejection criteria based on these PD histograms are now emerging and the electrically superior potting resins can be chosen.

Life testing for further correlation of PD behavior with life of a given sample has begun. With dc applied voltage, it is apparent that failure is much more probable during the brief successive turn-on ramps, where also the PD rates are greater than during prolonged exposure at steady dc voltage on the highest voltage plateau. Life testing will continue and superimposed ac on dc testing of PD behavior is planned for the near future.

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Sponsor: Office of Aeronautics and Space Technology

Advanced Thermal Transport Devices

New thermal transport devices are required for applications on a large Space Station where high power sources can be remotely located from their heat rejection surfaces. Conventional systems, such as those used on the Shuttle, utilize large energy consuming pumps to circulate a liquid for energy transport. As a replacement for these pumps new devices are under development which use the surface tension forces, established in a fine pored capillary wick, to drive the liquid.

These devices called capillary pumps, require no power and do not have moving parts that could wear out. In addition, by using common refrigerants with a high heat of vaporization, such as freon or ammonia, energy can be transferred at nearly a constant temperature. This allows a user of the system

to place equipment anywhere in the loop without concern for temperature variation. Recently a capillary pump system was assembled at the GSFC which carried 2000 watts over a distance 10 meters, at room temperature. It is hoped that a prototype system will evolve which will be flight tested on the Shuttle and incorporated into the design of a Space Station.

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Microwave/Millimeter Wave Communications

Technology is being developed that will result in space communication systems capable of transferring data at rates of thousands of megabits (gigabits) per second. Such systems will be necessary to relay large quantities of data from Earth orbiting instruments to the data user. To develop such systems, hardware is being developed in the areas of spacecraft frequency sources, modulator/exciters, high power transmitter amplifiers, low noise receivers, and other advanced subsystems including antennas.

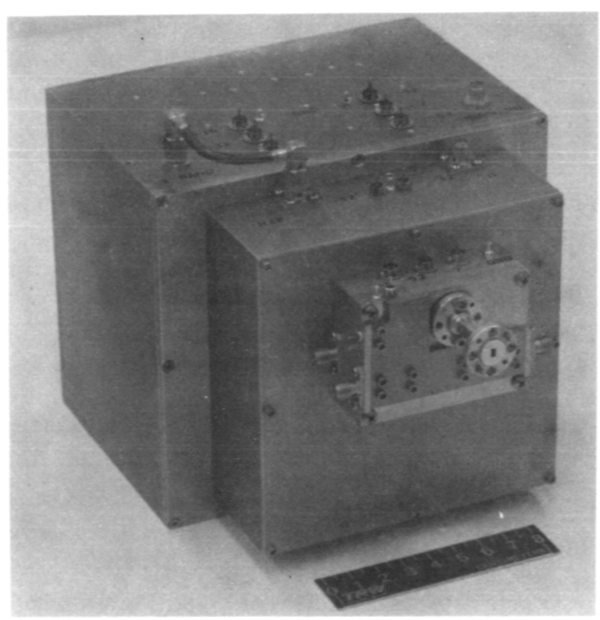
With regard to frequency sources, several hybrid microwave circuit Shallow Bulk Acoustic Wave (SBAW) oscillators have been developed, operating at frequencies of up to 2 gigahertz (GHz). SBAW oscillators show promise for spacecraft applications as they are lighter in weight and smaller in size than conventional crystal oscillators followed by multiplier chains.

High data rate communication links between spacecraft will use frequency bands around 60 GHz. An advanced breadboard 60 GHz modulator/exciter has been completed which includes a clock line receiver and modulator driver. This unit is capable of transmitting digital data at rates of up to 4 gigabits per second.

Reliable, high power solid state amplifiers for intersatellite transmitter applications are also being developed. A 4-watt 60-GHz amplifier using Impact Avalanche Transit Time (IMPATT) devices has been completed. The amplifier was designed to exhibit reliability for an operating lifetime in excess of 10 years.

Low noise, wideband receivers have been developed for operation at 30 GHz using Gallium Arsenide field effect transistors. These receivers exhibit state-of-the-art performance in terms of their sensitivity. At 60 GHz, receivers employing mixer front ends have been developed. Work is underway to integrate all Radio Frequency (RF) components on a single substrate including the RF mixer, local oscillator, coupler, and harmonic mixer, along with various filters. To develop extremely low noise millimeter wave receivers, several superconducting tunnel junction devices have been produced, and RF mixing at 115 GHz has been achieved. Theory and recent experimental results show that such devices can have a sensitivity approaching the fundamental quantum noise level.

In the area of high technology antenna development, work is underway to design high gain multibeam antenna systems for 60 GHz intersatellite



High-power, solid-state amplifier.

communication links. A dedicated microprocessor will be used for beam acquisition and pointing.

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NASA Engineering Extendible Unified Software

NASA Engineering Extendible Unified Software (NEXUS) is an integrated set of computer programs whose function is to support the full sequence of activities encountered in many NASA engineering projects. This sequence spans preliminary design, design analysis, detailed design, manufacturing, assembly, testing, and servicing. The extendibility and unification of the NEXUS software are implemented by organizing the system as an arbitrarily large set of programs which can be accessed in a common manner through a single user interface. The provision of a uniform interface also makes it more convenient for an individual user to access any of the NEXUS functions.

The NEXUS user interface is a multipurpose interactive graphics program called NASCAD, for NASA Computer-Aided Design. NASCAD provides the user with the ability to construct, label, and display three dimensional geometric models. These models can be colored and can define the edges or surfaces of geometric objects. NASCAD also provides the user with commands to activate sequences of other NEXUS programs and to transfer NASCAD format data to or from these programs. To support its different features, NASCAD contains an interactive and extendible general purpose language which can be used to define new functions from sets of existing commands.

With its capabilities for building and annotating geometries, NASCAD itself provides the graphics support for the preliminary and detailed design functions of NEXUS. Other functions are supported by external programs that can either work with NASCAD format data or have pre- and postprocessors for data conversion. The finite element program NASA Structural Analysis (NASTRAN) provides design analysis support. The Automatically Programmed Tools (APT) Program supports the manufacturing process. There is a series of robot control programs to support hardware assembly and servicing. A statistical analysis program serves to analyze test data by correlating measurements with the predicted data obtained from the design analysis phase.

It should be noted that a major objective of NEXUS is to provide sufficient capabilities in the executive control and the individual functional modules as to be useful in a variety of actual applications and provide a framework for constructing additional capabilities. NEXUS is not intended to be a complete or static program, but to provide an effective means of applying to NASA engineering projects the constantly evolving capabilities of computer-aided engineering techniques.

Submission of NEXUS System to COSMIC

The accompanying software and documentation, which are to be submitted to the Computer Software Management and Information Center (COSMIC) for distribution, constitute the NEXUS system. The function of this system is to provide integrated computer support for design and manufacturing tasks on NASA projects.

Basically, the NEXUS system consists of the software for the NASA Computer-Aided Design (NASCAD) interactive graphics program and for a set of utility programs which interface NASCAD with other engineering automation programs. These include NASTRAN, a design analysis program, and APT, a Computer-Aided Manufacturing (CAM) program.

The associated versions of NASTRAN and APT have already been submitted to COSMIC. This is the first releasable version of NEXUS, and it is expected to undergo future modifications. It should also be expected that some of these future modifications to NEXUS will entail modifications to APT and NASTRAN.

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Sponsor: Office of Aeronautics and Space Technology

VEHICLE, SENSOR AND TECHNIQUE DEVELOPMENT

Vehicles

Balloons

Wallops Flight Facility has continued to support the NASA Scientific Balloon Program through the R&D effort advancing the understanding of scientific ballooning. In 1983, two major areas were advanced: (1) the development of a small strain, nonlinear, viscoelastic model for the characterization of balloon film; (2) the survey and evaluation of available finite element models (FEM's) as well as the theoretical development of a dual curvature element for use in balloon FEM studies.

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Sponsor: Office of Space Science and Applications

38,000 Cubic Foot Tethered Aerostat

As part of its support for the NASA Scientific Balloon Program, Wallops Flight Facility acquired a 38,000 cubic foot tethered aerostat capable of supporting a 400-pound payload at 5,000 feet. Static ground acceptance testing of the aerostat and support equipment was accomplished in October and November of 1982. Flight acceptance testing was conducted on November 17, 1982. Scientific flight support for "Project Hy-Wire" was conducted in November 1982 and April 1983.

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High Altitude Powered Platform

In support of the development of new and improved experiment platforms, Wallops Flight Facility has concluded its feasibility study for a High Altitude Powered Platform (HAPP) concept. HAPP, a Lighter-Than-Air (LTA) concept will provide station-keeping experiment capability utilizing power derived from a microwave power beam transmitted from the ground. Flight durations of 3 months or more are predicted.

The Ground Microwave Power Transmission System (GMPTS) Design Report and Phase I and Phase II Reports, of a 2-phase vehicle study were received. The GMPTS report concerned itself with the design for the power transmission system for use with the HAPP. Phase I developed a complete and integrated set of system characteristics including operational criteria for the microwave powered HAPP. Phase II developed the design specifications for a proof-of-concept model of the HAPP as conceived in Phase I. This activity was recently completed with the results published in NASA CR 168344 and under NASA Contract No. NAS6-3131.

Stratospheric Reel Down/Reel Up Platform

Wallops Flight Facility is continuing its effort to provide increased capabilities and support for the NASA Scientific Balloon Program. In September 1982, the first launch of a new support platform for scientific payloads took place from Palestine, Texas. The support platform was a newly designed stratospheric reel down/reel up device capable of repetitively lowering and raising a 100-lb payload 15 km through the stratosphere.

The purpose of the test flight was to: (1) determine the dynamic behavior of the balloon, winching platform, and suspended payload at altitude; (2) test the newly designed winching mechanism for mechanical and/or electronic flaws; (3) diagnose flow conditions through a newly developed instrument flow tube geometry. On September 15, 1982, the balloon-winch-suspended payload ascended to 41.5 km. Following float stabilization, the 135-lb suspended payload was successfully lowered and raised 12 km through the stratosphere. The flight was successfully terminated and the payloads were successfully recovered.

Results of the flight revealed the following critical points:

- The entire system was exceedingly stable—there was a virtual absence of horizontal and rotational motion with less than a 2-percent deviation from 1 g acceleration.
- The scientific instruments on the suspended payload operated perfectly, and the newly developed instrument flow tube geometry established laminar flow through the instrument core.

This activity was recently completed with the results published under NASA Contract No. NAS6-3061.

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New Low-Cost Mid-Air Recovery Parachute

An existing low-cost high-altitude parachute is being modified for use in mid-air recovery of Sounding Rocket Payloads. The 63.5-foot diameter cross parachute is constructed of low-cost nylon and is capable of replacing relatively expensive mylar parachutes for high-altitude deceleration and mid-air recovery. The new parachute has the versatility to be employed as a high-altitude decelerator for payloads requiring slow descent rates as well as a low-altitude recovery parachute following payload ballistic reentry.

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New Three-Stage Sounding Rocket Vehicle

A new three-stage sounding rocket vehicle is being developed to provide a low-cost, high-altitude flight platform. The Taurus-Nike Tomahawk (TNT) launch vehicle will provide 700 km-plus altitude capability for lightweight payloads (60 to 80 lbs.). This new launch vehicle will be capable of achieving 150 to 200 km higher altitudes than attainable using the existing 2-stage Taurus-Tomahawk launch vehicle at a very modest cost increase. The TNT vehicle will be utilized to support a new class of relatively lightweight payloads requiring high-altitude flight.

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Sponsor: Office of Space Science and Applications

Sensors

The Giotto Magnetic Field Experiment

The Giotto Magnetic Field Experiment has been developed as part of a joint effort with the Technical University of Braunschweig and the University of Cologne (both in the Federal Republic of Germany) and the University of Rome (Italy). The instrument will be launched in 1985 aboard the ESA Giotto spacecraft and will provide triaxial measurements of the vector magnetic field before and during the Halley comet encounter in July 1986. The total experiment mass and power are 1.2 kg and 1.2 watts making it the most compact, lowest power, high performance dual magnetometer experiment built to date by the GSFC and the University of Braunschweig. Two fluxgate magnetometer systems are used with a dynamic range of ±16 nT to ±65.536 nT and a resolution of ±0.004 nT to ±32 nT. In addition, a microprocessor-controlled digital system provides autonomy and memory storage (64K).

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Sponsor: Office of Space Science and Applications

Galileo Probe Mass Spectrometer

A mass spectrometer in the Galileo Probe will directly and repeatedly sample Jupiter's atmospheric gases at different altitudes as the Probe descends.

The Jovian atmosphere is comprised primarily of 90 percent hydrogen and 10 percent helium; it also includes minor amounts of the inert gases neon, argon, krypton, and xenon, and noninert gases such as water, methane (CH_4), ammonia (NH_3), hydrogen sulfide (H_2S), acetylene (C_2H_2), and ethane (C_2H_6), as well as other trace constituents.

Atmospheric gases will enter the mass spectrometer through two inlet ports at the apex of the Probe. These ports will be sealed by metal-ceramic devices and kept under vacuum until the Probe enters the Jovian atmosphere. Pyrotechnic devices will then release the covers, allowing atmospheric gases to enter and be pumped to the test cells.

With its broad mass and sensitivity range, the instrument measures almost everything that enters it, making it ideal for this exploratory mission. The normal range of ion masses to be covered will be from 1 to 52 AMU (atomic mass units) with occasional sweeps from 1 to 150 AMU to search for heavier compounds.

The spectrometer will separate hydrogen from the gas samples to raise the relative abundances of the remaining gases in the sample. The instrument includes two "enrichment" cells. Some gas passes through the enrichment cell where substances called "getters" adsorb trace gases such as hydrogen sulfide, phosphine, and complex hydrocarbons until only the noble (inert) gases remain. The noble gases are admitted to the ion source for analysis. The enrichment cell is then heated, the adsorbed gases are desorbed, and the gases are admitted to the ionization region for analysis of the more complex compounds.

The instrument is being developed and built at NASA/Goddard Space Flight Center. It weighs 11.8 kilograms and requires approximately 25 watts, about half of which is consumed in pumps and heaters in the sample inlet pumping system.

The Engineering Unit instrument has been installed on the Galileo Probe and is undergoing environment tests. The Flight Unit instrument will be delivered in early 1984. The launch of the Galileo Orbiter/Probe is scheduled for the Shuttle Transport System (STS) in early 1986.

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Sponsor: Office of Space Science and Applications

Linear Array Pushbroom Radiometer II

The Linear Array Pushbroom Radiometer II (LAPR II) is an instrument developed in support of the overall multispectral linear array (MLA) program. LAPR II utilizes 512 elements, solid-state arrays developed by Westinghouse. Four arrays are used in tandem to collect spectral data from four spectral regions simultaneously. The instrument employs selectable rotating filter wheels, giving the capability of viewing up to 24 spectral bands, but only four at a time. The instantaneous field of view (IFOV) is 1.52 milliradians. The instrument is pointable fore and aft, as well as side to side. The detectors are silicon photodiodes which have a useful spectral sensitivity from blue in the visible out to the near infrared. The four arrays are thermoelectrically cooled to +5°C to reduce and stabilize detector gain and offset variations.

The data resolution is one part in one thousand. The instrument has a variable scan rate so that contiguous scans of the Earth are obtainable for various aircraft altitudes and velocity.

These imaging devices are being designed to replace the older mirror scanning systems. Linear arrays are predicted to have a longer life because no continuously rotating scanner is needed, but also the array should provide a lower noise signal since each resolution element of the image line is recorded simultaneously for the linear array, whereas the scanner must record each element individually.

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Sponsor: Office of Space Science and Applications

Earth Observation Sensors

The state of microelectronic technology has reached a point where linear detector arrays can be considered practical for use in space sensors. Technology advances have also made possible the placement of microelectronic multiplexers adjacent to the array, on the focal plane for the purpose of signal processing.

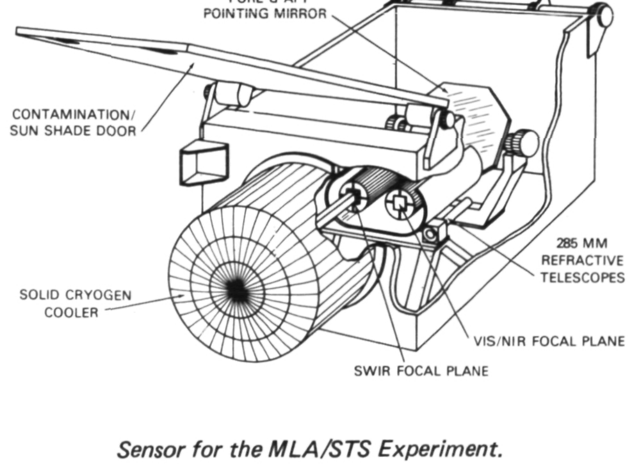
Three major programs are underway to further develop linear array detector technology for use in Earth-viewing imaging radiometers. Using the well developed silicon integrated circuit technology base, multiarray modules with detector elements that are sensitive to visible (0.4 - 0.7 μm) and near infrared radiation (0.7 - 1.0 μm) are being designed, fabricated and tested. Each of the approximately one-half-inch-square modules will contain four linear arrays of 1024 elements spaced 15 μm apart. Each of the arrays will be overlaid with a multilayer interference filter to delineate the spectral region to be viewed by the sensor. The modules are designed to be the basic units for forming arrays of several thousand elements in the focal plane of the sensor telescope. Similar silicon modules are being developed in a second program for the short wave infrared spectral region (1.0 - 2.5 μm). This program is based on the newly developed Schottky barrier technology and will result in modules having two linear arrays of 512 elements spaced 30 μm apart. A second development for the short wave infrared will design, fabricate, and test 512-element mercury-cadmium-telluride (HgCdTe) linear arrays with 30 μm element spacing that will be attached to silicon chips containing the required multiplexer electronics. This use of two materials is designated as hybrid technology. Each of the three programs will develop fully operational modules, demonstration focal planes having five closely butted modules, and, in the case of the HgCdTe program, a 6200-element focal plane array will be developed and tested.

MLA technology is also being pursued for application to the thermal infrared spectral region (8 - 12 μm). Photovoltaic HgCdTe linear detector arrays capable of operating at 105°K are nearing completion. Such devices will be suitable for future spacecraft sensors and should open many new possibilities for high resolution Earth and planetary thermal sensing applications.

In order to verify the performance of the modules developed by these programs and to intercompare them with linear arrays from other sources, a focal plane assessment laboratory is being developed. The laboratory will be capable of measuring and analyzing a wide variety of detector array performance parameters for both room temperature and cryogenically cooled devices. The goal of this laboratory is to develop a facility having the required support electronics, optics, calibrated radiance sources, mechanical fixtures, and data handling and analysis hardware and software to be able to fully characterize the widest possible variety of detector arrays.

The first spaceborne demonstration of this technology has been proposed for the MLA/STS Experiment, a 6-channel imaging radiometer slated for flight on the Shuttle in late 1987. The sensor will utilize two of the four-array visible/near IR modules and two of the Schottky barrier shortwave IR modules to view a 30-kilometer swath with 15- and 30-meter spatial resolution respectively. The data from this experiment will be used to examine the optical and biological properties of terrestrial land cover.

Most of the major goals in Earth Science research require data sets over time periods longer than presently available from the Shuttle. Therefore, the ultimate goal for MLA technology is its utilization in a versatile imaging radiometer for use on a free-flying platform. Such a sensor would be a direct descendant



Sensor for the MLA/STS Experiment.

of the MSS and TM with added emphasis on research tasks. As an aid in determining the present technological limits of such a sensor, a design study for a Research Optical Sensor (ROS) is being initiated. The emphasis in this study will be on incorporating as much versatility as possible into the sensor design in order to cover the widest possible range of Earth science remote sensing experiments.

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Sponsor: Office of Space Science and Applications

Airborne Oceanographic Lidar

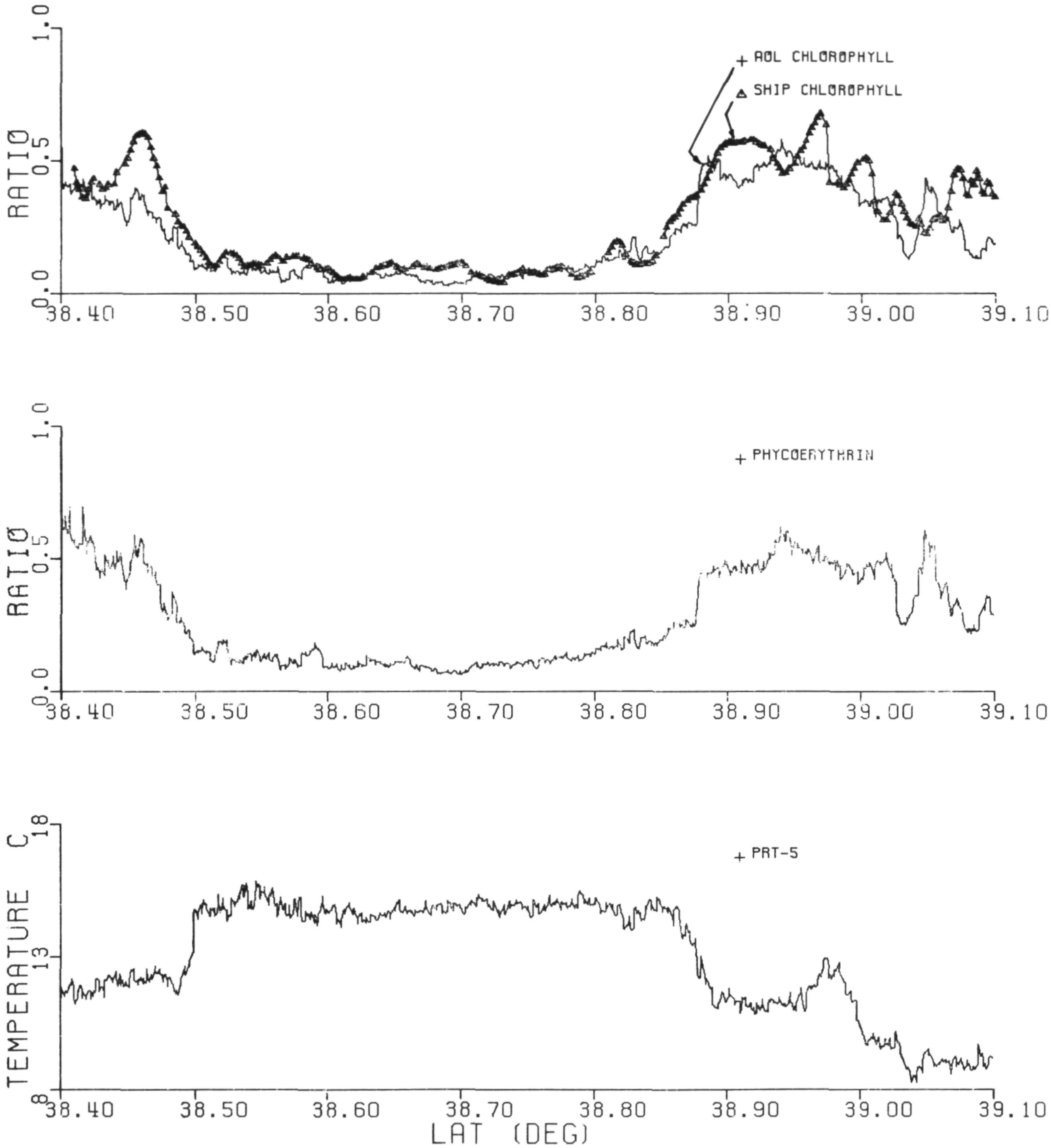
Research activities with the Airborne Oceanographic Lidar (AOL) at GSFC/Wallops Flight Facility concentrated on improving the capabilities of the instrument in both of the basic modes of operation. In the fluorosensing mode, the AOL provided remote sensing support for the multiinstitutional Gulf Stream Warm Core Ring Study. The other institutions include Scripps Institution of Oceanography, Bigelow Laboratory for Ocean Sciences, and the University of Rhode Island. During these experiments, a total of five flights were conducted over Warm Core Ring 82-B to provide nearly synoptic assessments of the distribution of water transmissivity, as well as chlorophyll and other photo-pigments associated with marine phytoplankton. In addition, AOL subsystems were used to acquire water surface temperature with an infrared radiometer and water column temperature profiles with an expendable bathythermograph.

The figure shows an example of data acquired during a transect across the ring during a mission flown on April 20th. The temperature profile shows the typical water surface temperature contrast during the spring between a warm core ring and the surrounding shelf and slope water masses. Note also, the high phytoplankton activity (as shown by the chlorophyll and phycoerythrin profiles) associated with the ring boundary regions where nutrient-rich shelf water becomes warmed and even entrained within the ring. The chlorophyll measurements obtained along the transect line from one of the participating ships are plotted along with the AOL chlorophyll profile. Considerable agreement between the two profiles can be seen despite the more than 12-hour time difference between the airborne and ship transects.

In the bathymetric mode, research efforts continued toward extending capabilities of the AOL to include terrestrial applications such as providing overland surveying as well as forestry and crop inventory information. In this mode of operation, the laser backscatter is time-resolved to yield the location of tree canopies or other biomass and the ground surface all relative to the aircraft. Aircraft motion is then removed with a recently developed technique using data from a vertical accelerometer so that the foliage and terrain features are shown in a proper perspective. Experiments designed to develop and examine the potential of airborne lidar technology in these areas have been conducted jointly with the U.S. Army Corps of Engineers (COE) and the U.S. Forestry Service. In addition, some cooperative experiments have been conducted with COE in order to determine the feasibility of using the AOL in a bathymetric mode to detect military vehicles located in wooded terrain.

A new initiative has been undertaken in the area of overland forestry and crop surveying. This work involves the utilization of the laser fluorosensor for extracting information on chlorophyll and other photo-pigments during transects flown over various target areas. Preliminary laboratory and flight tests indicate that this application is both feasible and has significant potential application for both forest and agricultural management. In addition, joint work with COE is expected to continue.

Instrument improvements during the past year include the addition of a passive color subsystem to the fluorosensor and a higher resolution waveform digitizer to the bathymetric subsystem. The passive mode is operated simultaneously with the active fluorosensor. Solar reflectance spectra are thus obtained between pulses when there is no laser-induced fluorescence spectra. Data of this type are expected to improve the present understanding of certain algorithms for deriving chlorophyll concentrations from passive sensors.



Temperature, chlorophyll and phycoerythrin profiles.

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Sponsor: Office of Space Science and Applications

Optical Sensor Research

Significant improvements in the measurement of basic atmospheric parameters are required for improved weather forecasting, the prediction of climate change, and increased understanding of atmospheric processes. GSFC is conducting advanced research on a number of new remote sensing techniques. These include the development of new lidar techniques for the measurement of atmospheric pressure, temperature, density, carbon dioxide, boundary layer, and cloud properties, as well as conducting high resolution spectroscopic measurements.

There is a requirement for remote measurements of the atmospheric pressure field and for improved measurements of the atmospheric temperature profile. Although pressure is one of the fundamental atmospheric state variables, there are no current remote sensing techniques for measurement of the pressure field. Thus, important forecasting tools such as maps of surface pressure and 500 mb height contours must be produced either by *in situ* measurement or by indirect methods. The development and application of temperature sounding to improve the understanding and forecasting of weather is a major thrust of NOAA and NASA meteorological programs. The capabilities of current passive sounders have not been able to meet the required accuracy level of 1°C, and the development of new techniques, such as lidar sounders using pulsed lasers, is needed.

New lidar techniques for the measurement of atmospheric pressure and density profiles, surface pressure, and temperature profiles have been developed at the Goddard Space Flight Center. Field measurements using continuous wave lasers have demonstrated measurements of surface pressure to accuracies of 1 mb and temperature to accuracies of 0.6°C. A pulsed laser experiment for measuring vertical profiles of pressure and temperature from ground-based and aircraft platforms has been constructed, and initial measurements of the atmospheric pressure profile were successfully demonstrated using a dual laser system. This is the first time a continuously tunable high energy solid-state laser (Alexandrite) has been used for measuring atmospheric properties. The development of this new technology will allow the extension of these measurements from field experiments to satellite application using compact, efficient, high reliability laser systems.

Theoretical studies which have been conducted that support this work include: a detailed analysis of the lidar temperature method; the development of a new technique for measuring atmospheric density; a comprehensive analysis and solution of the problem of laser finite bandwidth for the lidar measurement; and, initial studies of the effects of inelastic scattering processes on lidar absorption experiments.

The feasibility of lidar measurements of the distribution of atmospheric CO_2 has also been investigated and initial laboratory experiments have been successfully conducted. In order to understand how much of the excess CO_2 is recycled by vegetation and by solution in the cold sea surface of polar areas and in regions of upwelling, CO_2 measurements are required diurnally.

The development of airborne lidar for cloud radiation and storm dynamics studies has produced successful results. Over the past several years a lidar system has been deployed on high-altitude aircraft cloud observation missions. The acquired measurements include a wide variety of cloud-top structure observations. These data graphically present the height resolved structure of storms in a manner not previously realized and have proven a useful adjunct to *in situ* and other remote sensing observations. Analysis development is in progress to obtain the maximum interpretation of data in terms of cloud particle parameters and to corroborate simultaneous passive remote sensing observations for study of cloud radiation parameterization.

Goddard researchers have also developed a laboratory which has the capability to measure molecular line parameters with a unique, cold optics, 3-meter focal length grating spectrometer which operates from 1 to 30 μm and also with a tunable diode laser spectrometer. Extensive measurements and analysis of the spectrum of H_2S have been conducted with the tunable diode to gain a better understanding of water vapor. We have also successfully obtained the first spectra from the cold optics instrument. Selected measurements of CO, CH_4, and OCS have been made in both the 2 and 10 μm (1000 cm^{-1}) spectral regions. A resolution better than 0.017

cm^{-1} has been demonstrated in both regions. This is the highest resolution obtained beyond 5 μm with a grating spectrometer and shows, in part, the signal-to-noise enhancement obtainable with the use of cold optics.

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Sponsor: Office of Space Science and Applications

Techniques

Very Long Baseline Interferometer

The Very Long Baseline Interferometer (VLBI) group at Goddard Space Flight Center has developed, operated, and refined the Mark III VLBI System. The system has been made available to the worldwide geodetic community through commercial sources nurtured by this project.

Between 1975 and 1980 the Goddard VLBI group developed and successfully demonstrated the Mark III VLBI System in conjunction with colleagues at the Haystack Observatory. In a concentrated series of 14 tests in late 1980, the group demonstrated that the Mark III can achieve geodetic precision of one part in a hundred million or better.

Since 1980 the group has concentrated in two areas: continuing a series of critical geodetic measurements, and providing the system to other groups both inside and outside NASA.

Measurements made since 1980 on the Fort Davis (Texas)–Owens Valley (California)–Westford (Massachusetts) transcontinental triangle demonstrate that motions within the North American plate are less than one centimeter per year. Within the next year measurements from North America to Europe should determine whether continental drift between the North American and European plates is continuous or episodic.

In late 1980 the National Geodetic Survey (NGS) with NASA's help began to implement an Earth rotation monitoring service using the Mark III VLBI System. This service is now running routinely on a weekly basis, and the NGS no longer needs close NASA support. Within the next year the new service will render the current international Earth rotation service based on optical measurements obsolete.

The Goddard group has cooperated with JPL in developing a mobile configuration of the Mark III VLBI System. The mobile systems are now being used intensively to make geodetic measurements in the Western United States.

Geodetic institutes in Europe and Japan have selected the Mark III VLBI System as the new standard for making worldwide geodetic measurements. Institutes in Germany, Japan, England, and Italy have purchased Mark III VLBI Systems from the Goddard-developed commercial sources.

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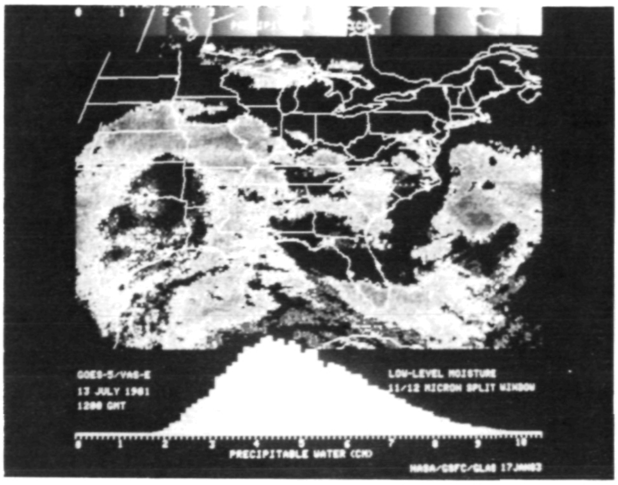
Sponsor: Office of Space Science and Applications

A Technique for Observing Water Vapor at High Resolution

NOAA's geosynchronous weather satellites (GOES) now carry a NASA-developed 12-channel radiometer called the VISSR Atmospheric Sounder (VAS). Filters are used to observe molecular absorption bands in the far infrared in order to determine the vertical temperature and moisture structure of the atmosphere. The geosynchronous station is exploited to take hourly views of the United States at 15-km resolution. Unfortunately, the use of all 12 VAS channels interrupts the preestablished VISSR mode which produces the visible and single-channel infrared images normally seen on television. Fortunately, extra detectors on the new VAS instrument may be used to observe at 2 or 3 wavelengths without interfering with NOAA's standard operations. Even in this limited mode, we have developed a *quantitative* measurement of the total water vapor content at each field of view in any VAS frame which contains the "split window" channels at 11 and 12 μm. The differential water vapor absorption



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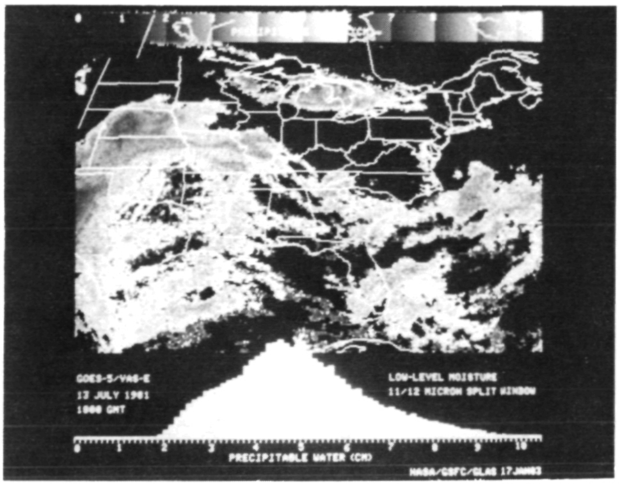

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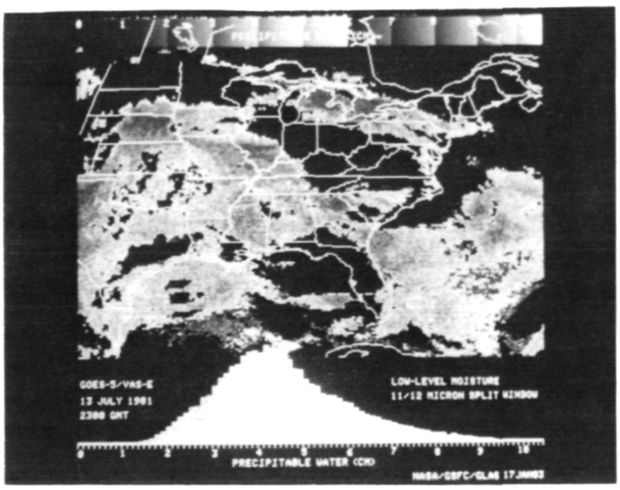

C

Image sequence of low-level water vapor field estimates made from the VAS split window over the United States at A) 12000, B) 1800 and C) 2300 GMT on July 13, 1981.

in this part of the infrared spectrum makes the 11-μm radiance closer to the underlying surface temperature while the 12-μm brightness is closer to the overlying air temperature, both by an amount controlled by the moisture content. Indeed, the two channels were originally designed to provide a moisture-corrected value of sea surface temperature (SST), but the inverse of the radiation transfer equation allows us to calculate both surface temperature and moisture content, even over land.

The figure shows a test of the algorithm for 3 VAS frames taken at dawn, midday and dusk over the United States in midsummer. Cloudy fields of view have been detected as cold pixels, and have been colored black. The precipitable water (in cm) of the clear pixels has been placed on a numerical gray scale (dry in dark). Histogram statistics have been displayed to demonstrate the stability of the results throughout the day. The persistence of very detailed features demonstrates the good relative accuracy of the satellite-derived moisture patterns. Dramatic changes occur on normally unobservable scales as small as 100 km. For instance, there are developing dry areas in western Nebraska and northern Georgia, a dry slot across Missouri, and a very wet area in eastern Iowa. Iowa demonstrates the potential value of VAS data for making local severe storm forecasts in a locale which has no conventional upper-air weather observations—the morning clouds dissipate, leaving a deep, moist layer to be heated by the afternoon Sun. Later that evening (after VAS was turned off), severe thunderstorms occurred in this convectively unstable area.

VAS moisture fields can be produced as frequently as every 15 minutes, around the clock. In fact, time-lapse movies have already been made during the VAS postlaunch checkout period. Overlays by the upper-air VAS channels can locate unstable areas, where dry upper-air winds blow across deep layers of low-level moisture to form a prestorm environment. Operational use of the VAS instrument is being debated by NOAA.

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Sponsor: Office of Space Science and Applications

Surface Contour Radar

The Surface Contour Radar (SCR) is an airborne, computer-controlled radar operating at a frequency of 36 GHz (8 mm wavelength). This instrument can produce a real-time topographic map of the sea surface beneath the aircraft. The map appears as a color-coded display on a TV monitor. Postflight programs remove any aircraft vertical motion from the data and then through a Fourier Analysis wave direction and height are calculated. These directional wave spectra are generally available the day following the flight.

The directional wave spectra measured have contributed to several projects: a major acoustical field experiment in the North Atlantic, a study of conditions in the vicinity of a hurricane and the Marine Air-Sea Exchange Experiment (MASEX) off the Atlantic Coast. This radar was able to measure the evolution of the wave spectra as a function of wind field (fetch) and to demonstrate the presence of waves emanating from an embayment. Detailed comparisons have shown the significantly higher angular resolution of this aircraft system compared to the pitch and roll buoys that are usually used for directional wave spectra.

Since the SCR measures both range and backscattered power simultaneously, it is also well suited for radar backscatter investigations. The system has already been used to measure the electromagnetic range bias that a satellite radar altimeter would be subject to in the presence of ocean waves. A study is underway to determine the transfer function relating radar backscatter at 36 GHz to local slope, deviation from mean sea level, off-nadir incidence angle, phase angle relative to the dominant sea surface waves, and azimuthal angle relative to the local wind. These variables are necessary to understand as we increase our monitoring of the ocean from space.

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Sponsor: Office of Space Science and Applications

INFORMATION EXTRACTION

Facilities

National Space Science Data Center

The National Space Science Data Center (NSSDC), administratively a part of the Sciences Directorate at Goddard, is responsible for the acquisition, archival, and dissemination of space science data. In addition to its basic functions, NSSDC offers "value-added" services to the scientific community to further facilitate scientific research.

As examples of this, NSSDC has created and distributed three separate multidata set products during the past year. The first of these is a 5-min resolution, IMP-8 solar wind field and plasma compilation for the period 1977 to 1979. This interval marked the most active data acquisition phase of the International Magnetospheric Study (IMS). Easy accessibility to data on solar wind variations which drive magnetospheric processes is particularly valuable in the ongoing IMS data analysis phase, and the 5-min IMP-8 compilation provides this easy access. The second example is an hourly resolution, multi-spacecraft, near-Earth solar wind field and plasma data compilation now spanning the years 1963 to 1982. During this past year, an update from 1978 to 1982 was performed, which required an extensive analysis of uncertainties involved in propagating ~1-hr-upstream ISEE-3 field and plasma data to the Earth's vicinity. Finally, composite field and plasma data sets from deep space missions (Helios, Mariner-10) were created in a common format and were disseminated. One useful mode of information presentation implemented for these last data sets involved color-coded, 27-day line plots which made high speed streams and heliospheric current sheet crossings and their recurrences highly visible.

Another noteworthy example of "value-added" service provided by NSSDC are Coordinated Data Analysis Workshops. In these exercises, NSSDC has built data bases to address important physical questions, from data acquired during particularly interesting periods by several spacecraft and ground-based instruments. NSSDC has also built software to enable scientists to access, manipulate, and plot parameters from these data bases in near real time. Activity related to the CDAW-6 data base, aimed at understanding magnetospheric substorm energy release mechanisms, continued during this past year. Several oral presentations have been made at scientific meetings, and many scientific papers are in progress.

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Sponsor: Office of Space Science and Applications

Science and Applications Computing Facility

The Science and Applications Computing Center (SACC) provides general purpose computational services to support scientific research at Goddard. SACC utilizes an IBM 3081 as its central processor.

The 3081 is IBM's most advanced main-frame processor and utilizes a highly integrated circuit technology packaged in Thermal Conduction Modules (TCM's). The TCM is a helium filled, encapsulated module, measuring 125 × 134 × 35 millimeters, and contains tens of thousands of logic circuits. Benefits of the new technology include significant reductions in space, power, and cooling requirements.

A significant milestone was accomplished in FY83 when a 236-gigabyte IBM mass storage subsystem was installed in the facility to allow interactive scientific analysis of very large data bases. Pilot projects are now underway to develop and document guidelines and techniques to use the new capability. Initial data base applications include archival spectra from the International Ultraviolet Explorer satellite, hourly averaged field and plasma data most frequently requested from the National Space Science Data Center, and magnetometer data from the Voyager spacecraft.

The overall strategy in continuing the upgrade of the facility is to support a highly adaptable environment for evolutionary growth and to exploit advances in technology as they are available and appropriate.

In line with this strategy, FY84 plans call for upgrading the central processor from a Model D to Model K. This will result in a 40 percent increase in processing capability for a 10 percent increase in cost. The upgrade will be accomplished through an overnight field engineering change and will greatly enhance interactive support to scientists.

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Sponsor: Office of Space Science and Applications

Massively Parallel Processor (MPP)

The Massively Parallel Processor (MPP), delivered to NASA/Goddard Space Flight Center in May 1983, uses a custom-designed Very Large Scale Integrated (VLSI) chip to implement its Single Instruction Multiple Data stream (SIMD) architecture.

The High Speed Complementary Metal Oxide Silicon (HCMOS) VLSI chip is used as the basic building block to form the 128 × 128 array of bit serial processors. Each VLSI chip contains eight processors, thus enabling the 16,384 processors plus commercial memory chips (1024 bits/processor), interface chips, and four columns of extra processors to fit into a 38-inch cabinet. Array control computers and a large data buffer fit into an adjoining cabinet.

MPP was built to demonstrate the power of spatially parallel computers in image processing where operands are often small integers and where MPP, due to the bit serial nature of its processors, has highest performance. Image processing benchmarks, chosen for their parallel properties, have shown MPP to have three orders of magnitude

higher performance than a VAX 11/780 for data sets fitting into its array memory (two megabytes).

In addition, MPP can perform floating point operations in its array. A numerical simulation, again chosen for its parallel properties, has shown MPP to have more than two orders of magnitude higher performance than an Amdahl V6 for data sets fitting into its array memory.

In FY83, MPP will be operating under control of a high-level language, Parallel Pascal, and will begin to use its data buffer to allow it to process data sets larger than two megabytes. MPP is beginning to be made available to selected scientific users and will become available on the Arpanet in late FY84.

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Sponsor: Office of Aeronautics and Space Technology

Landsat Assessment System

The Landsat missions, through the July 1982 launch of Landsat-4, have carried various imaging sensors for observation of the Earth and its resources in visible and infrared wavelengths. The preparation of scientifically and operationally useful data from these instruments is the prime function of the ground systems associated with the spacecraft; the critical components of such ground systems provide data geometrically and radiometrically corrected to high precision. The Landsat-4 spacecraft carries, in addition to the Multispectral Scanner (MSS) flown on previous Landsats, a new high-resolution scanning device, the Thematic Mapper (TM). This sensor presents unique complexities and possible difficulties to the ground systems. Because of the lack of experience with the TM and the requirement to maintain the quality of corrected data, a separate facility was established within the Landsat-4 ground segment to evaluate the performance of the sensor and ground processing corrections. This facility, the Landsat Assessment System (LAS), is also being used as an analysis tool to evaluate the utility of the TM data in discipline investigations, especially as quantitatively compared to MSS analyses.

The LAS, completed for initial use in July 1982, included complete software capabilities for the evaluation of the ground segment TM image data correction from raw to geodetically and radiometrically precise outputs, as well as limited production of image scenes for evaluation both at the LAS and at other institutions. The LAS has been sized to accommodate meaningful quantities of TM data and includes equipment components for the production of high-quality film as well as digital data products. Analysis software includes classical image processing functions derived from other systems, such as enhancements, filtering, classification, and image display to three interactive image analysis stations. The data from other sensors, including the MSS, are amenable to analysis on the LAS.

During 1983 and 1984, the system will be upgraded to include a geographic entry system, a geographic information system, and additional information extraction algorithms in support of Landsat and other instruments. Plans are being formulated for a high-speed data bus connection to the Massively Parallel Processor (MPP) to accommodate algorithms that are computationally untenable on the LAS VAX/AP-180V hardware.

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Sponsor: Office of Space Science and Applications

Regional Applications Program

The Eastern Regional Remote Sensing Applications Center (ERRSAC) Regional Applications Program (RAP) completed cooperative demonstration programs with Maine and Wisconsin during the year. Eleven states in the northeast/northcentral area have now successfully concluded programs and have operational capabilities for using satellite remote sensing data in environmental and natural resource mangement. Programs in four additional states and Puerto Rico are now underway, and completion is anticipated in FY84. This will complete the program.

Remote sensing working groups established in Maryland and Ohio meet quarterly to coordinate and guide interagency activities.

In Maine, forest inventories of the Moose Lake area were completed using 1975 and 1980 data; land cover changes that occurred between those dates were classified. Two projects were completed in Wisconsin in concert with the state university. These included a statewide inventory of public remote sensing capabilities and training facilities, and a combined agriculture/irrigated lands survey of Portage County.

The Regional Remote Sensing Center established at the University of Vermont is supporting current RAP activities with various state entities in New Hampshire, in addition to providing continuing services to state personnel in Vermont. This marks the initiation of sharing interstate facilities to optimize resources.

Emphasis during the year has been placed on documenting completed state projects, and 28 are now recorded and available for review in open file reports.

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Sponsor: Office of Space Science and Applications

High Speed Microdensitometer

The objective of this effort is to develop a high speed digital microdensitometer to satisfy increased photometric precision requirements associated with astronomical imagery.

The standard astronomical microdensitometer currently in use is capable of digitization at a rate of a few thousand samples per second at low photographic density and only a few per second at high densities (above 3.0D). The current photometric precision is the range of 0.01D. The first step in extending the capability will be to push current machines to their limits by replacing existing electronics with modern modules. It is anticipated that this will increase speed by a factor of 5 to 10 without significant decrease in photometric response.

In parallel with this, specifications for the next generation of astronomical densitometers are being developed. Results from a conference held on this subject at Goddard in May 1983, will form the basis for defining detailed requirements of the astronomical community for the next 10 years.

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Sponsor: Office of Space Science and Applications

Systems

Computer Networking

The purpose of this effort is to permit flexible and easily distributed computing by linking heterogeneous computers, peripherals, and terminals or workstations. The intent is to develop a local area network of integrated scientific computers and terminals using a robust architecture that will permit easy future expansion.

To the extent possible, this effort will apply and integrate commercially available network offerings in accordance with the ISO/ANSI Reference Model for Open System Interconnection (OSI). This model provides a common architectural basis for coordinating the various standards required for OSI. Any local tailoring or specialized development will be limited to areas where there are no widely supported standard protocols and will be isolated within layers of the OSI model to allow for consistent interfaces, portability to different environments, and modular replacement when and if widely supported standard protocols do become available.

The first step in a high speed host-to-host network will be accomplished in late 1983 with the implementation of two point-to-point, 56-kps data links interconnecting a VAX 11/780 and DEC PDP 11/44 to the SACC IBM 3081.

Plans for FY84 include linking selected terminals to the SACC 3081 processor at speeds of up to 19.2 kbps via the in-place CATV network. This will provide a testbed to evaluate use of broadband communications technology for graphical data analysis.

The network will then be expanded to include other computing facilities within the Sciences and Applications Directorates, along with gateways to remote sites.

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Sponsor: Office of Space Science and Applications

Data Base Management Research

GSFC is conducting various applied R&D activities in data base management systems (DBMS). The purpose of these activities is to assess, develop, and demonstrate techniques for applying DBMS technology to NASA's satellite data management problems and to transfer this technology to current and future missions. Fiscal Year 1983 activities included:

- Access Methods for Distributed Heterogeneous Data Bases—The purpose of this research is to develop a mechanism to enable scientists and administrators at remote sites to uniformly access data that are physically distributed and heterogeneous (i.e., relational, hierarchical and network). The system to support this goal, called DAVID (Distributed Access View Integrated Data Base) is currently under development. Technically, DAVID is a data base management system which is to be built on top of already existing data base and file management systems.

  The DAVID project is a coordinated effort led by the Information Management Branch at GSFC and comprised of several universities (Maryland, Catholic, Towson State, Stevens Institute and City University of New York). In Fiscal Year 1984, testing and development of DAVID will continue. In addition, investigations will be initiated that will use DAVID as a basis for developing and integrating expertise or knowledge-based information systems.

- Architecture—The objectives of this task are to define, investigate and recommend advanced concepts and DBMS architecture for rapid update and retrieval of information from very large multisource data bases. A study has been initiated to develop a conceptual design for a system to handle very large data bases.

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Sponsor: Office of Aeronautics and Space Technology

Pilot Climate Data Base Management System

The Pilot Climate Data Base Management System (PCDBMS) is being developed to serve as a focal point for managing a large collection of climate-related data, in particular NASA satellite data. The PCDBMS does this by providing uniform data catalogs and inventories, and access, manipulation, and display methods for selected NASA and supporting non-NASA data sets. The data manipulation capabilities allow research users to easily combine or compare data sets, and acquire data that are compatible with other computer facilities where the data will be used. This pilot system focuses current data management activities, demonstrates the capabilities of an automated data management system, provides limited but useful support for climate research, and supports related data base management research and development directed toward the evolution of a comprehensive, fully automated data management system.

In FY83, support was added for additional data sets, and new capabilities providing statistics and graphics for the supported data sets were developed. In FY84, support will be added for additional data sets, and additional statistics and graphics capabilities will be provided.

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Crustal Dynamics Data Information System

The Data Information System (DIS) for the Crustal Dynamics Project provides for cataloging of all Project-acquired data from 1974-1981, as well as new data to be acquired during the lifetime of the Project through 1988. The collection of the various types of data includes a large selection of analyzed geodetic data products, such as geodetic baselines, positioning of the observing stations, Earth polar motion data, and many other ancillary geodetic products. The information will be stored in a Crustal Dynamics Data Base and is directly accessible via a menu-driven user language. The DIS utilizes commercial data base management techniques to enable the user to query and cross-reference the information for the preparation of data requests and for providing project management reports.

After the completion of a conceptual design of the DIS in July 1981, the system implementation was started in FY82 with the design of the data base and the subsequent cataloging of the data products. Shared utilization of a VAX 11/780 computer with the Pilot Climate Data Base Management System enabled a rapid implementation of the system, including menu-driven procedures and user Help functions. Pilot operations for outside users through dial-up telephone lines were started in May 1982 and the system became fully operational in September 1982. The system has been used extensively since it became operational. Investigators and Project personnel regularly utilize the system for accessing geodetic data products and for preparation of technical reports. The DIS is expected to become part of the data base for the National Geodetic Reference System at the conclusion of the project.

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Sponsor: Office of Space Science and Applications

Nimbus-7 Climate Data Set Development

Now in its fifth year of operation, the Nimbus-7 satellite is producing several long-term climate-related data sets. In fact, Nimbus-7 is the single most significant source of experimental data from Earth orbit, relating to atmospheric and oceanic processes. Nimbus-7 data sets, once validated, are made available from Federal archives. These data sets are in various stages of development, and their status is presented below.

Data from the Coastal Zone Color Scanner (CZCS) consisting of radiance, chlorophyll, sediment, and sea surface temperature, and covering two and a half years, have been archived. Data production and validation continue.

Solar and Earth radiation data covering three years from the Earth Radiation Budget (ERB) Experiment have been produced and archived. Production of the fourth year of data has begun.

Limb Infrared Monitor of the Stratosphere (LIMS) Experiment data covering seven months (LIMS cryogen lifetime), and containing stratospheric temperature, ozone, water vapor, nitric acid, and nitrogen dioxide profiles, have been produced and archived.

A 4-year data set of stratospheric aerosols in the polar regions from the Stratospheric Aerosol Measurement (SAM II) Experiment has been archived. Data production and validation continues.

The first 2 years of global ozone data, consisting of vertical concentration profiles and total burden concentrations from the Solar Backscatter Ultraviolet (SBUV) and Total Ozone Mapping Spectrometer (TOMS) Experiment, have been archived. The production of the third year of data is nearing completion, and archival is scheduled for 1983. The production of the fourth and fifth years' data sets is underway, with archival of both years scheduled for 1984.

The production of the Scanning Multichannel Microwave Radiometer (SMMR) Experiment data continues and now extends into the fifth year of orbital data. The data consist of brightness temperatures and the following derived products: sea ice (multiyear ice fraction and sea ice concentration), total atmospheric water vapor over oceans, sea surface temperature, and sea surface wind speed. The first 2 years of data have been archived.

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Sponsor: Office of Space Science and Applications

Experimental Test and Evaluation Program

The NASA Experimental Test and Evaluation Program (ET&E), the successor to the Regional Remote Sensing Applications Program (RAP), was initiated in FY82. The objectives are to determine the technical viability of remote sensing techniques through test and evaluation projects in a variety of applications environments. The emphasis has been on improved interpretation of remotely sensed data, especially that which incorporates georeferenced data sets, in a generic multidisciplinary mode.

Permanent intensive test sites in the greater Washington-Baltimore area were established for 12 USGS 7.5-minute quadrangle map areas. This approach allows comprehensive testing of techniques in a controlled, cost-effective, multilayer, multisource, multiresolution geographic information system environment. This data base supported the following research projects: 1) The AVHRR/MSS Accuracy Assessment Project to evaluate the relative accuracy of AVHRR (1100-m resolution) versus MSS (80-m resolution) for Level I land cover characterization determined that MSS produced 76.8 percent correspondence with the ground truth, and the AVHRR 71.9 percent; 2) The Landsat-4 Thematic Mapper versus MSS Accuracy Assessment Project compared the Level I mapping capability. Success for TM was between 11 percent and 14 percent or about a factor of 1.3 for the data pair studied; 3) The HCMM/MSS Merger Project for improved separation and classification accuracy for the urban versus agriculture categories produced a 5 to 10 percent improvement.

In addition, the MSS Normalization Study determined that statistically significant improvements in land cover classification could be achieved by correcting data for sensor calibration and solar illumination differences. These results were achieved using a separate data base comprised of spectral signatures from 26 projects.

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Transportable Applications Executive (TAE)

Increasing software development costs and the difficulty of transferring programs between computer systems motivated an effort in 1980 to design a common executive to be used in software systems currently under development for remote sensing applications. This Transportable Applications Executive (TAE) will provide systems services commonly required by data analysis software, including interactive user control through menus, commands and command procedures, input parameter processing, error handling, and image and file management. Machine and operating system dependencies will be isolated in interface subroutines to facilitate conversion of the executive to other systems. Because of the common interface provided by the executive, analysis programs written to use its services can be installed and run on other computer systems operating under TAE.

Following completion of a conceptual design in November 1980, a prototype version of the system was completed in August 1981, which operates on Digital Equipment Corporation VAX 11/780 computers. During FY82, the prototype was converted to run on the DEC PDP-11 computer system. In FY83, the prototype was converted to run on a Data General Eclipse.

During FY83, a Memorandum of Understanding (MOU) was established with JPL to use TAE as the executive in the Multimission Image Processing Lab. JPL will contribute to the further development of TAE and we will exchange applications programs. A similar activity fostered by the commonality of TAE is being developed with the EROS Data Center. The prototype was released to the public through COSMIC. The operational version of TAE with a substantially augmented command language was produced and delivered to ten sites for beta testing. The operational version will be released to the public in early FY84. Work was also begun on two TAE subsystems to provide a device-independent image display package and a TAE network interface. TAE has been delivered to approximately 50 sites, and there are an additional 20 requests for new installations.

One of the first software packages to run under TAE is the General Meteorological Package (GEMPAK) currently under development to analyze temperature, humidity, and other parameters which are derived from satellite observations. This system of analysis programs provides capabilities for the mathematical analysis of observations and the ability to produce gridded fields and the display of contour maps, vertical soundings and cross sections. GEMPAK includes device-independent graphics subroutines that will be generalized for use in TAE to provide a common, transportable interface to a variety of color and monochrome display devices and plotters.

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Sponsor: Office of Space Science and Applications

Interactive Digital Signal Processor

The Interactive Digital Signal Processor (IDSP), implemented on a VAX 11/780 under VMS, consists of a set of time series analysis "Operators" each of which operates on an input file to produce an output file. The operators can be executed in any order that makes sense and recursively, if desired. The operators represent the various algorithms that have been used in digital time series analysis work over the years. In addition, there is provision for user written operators to be easily interfaced to the system. The system can be operated both interactively and in batch mode.

In IDSP a file can consist of up to n ($n \leqslant 8$) simultaneous time series. Thus storage for a file can be subdivided such that it is used, for example, entirely for one long single time series or for as many as n shorter time series, such as the components of a vector. An operator always operates simultaneously on all of the time series in a file.

IDSP currently includes over 30 standard operators that range from Fourier transform operations, design and application of digital filters, eigenvalue analysis, to operators that provide graphical output, allow batch operations, or edit and display information.

IDSP is being used extensively to process data sets obtained from scientific experiments on board spacecraft such as Dynamics Explorer, ISEE, IMP, and Voyager. In addition, IDSP provides an excellent teaching tool for demonstrating the application of the various time series operators to artificially generated signals.

IDSP is available from the Computer Software Management and Information Center (COSMIC), 112 Barrow Hall, University of Georgia, Athens, Georgia 30602, Program number GSC-12862.

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Sponsor: Office of Space Science and Applications

Graphics Technology

The purpose of this effort is to design and develop a scientist-friendly system for graphical display of data. The system will be transportable over a wide class of computers and usable with many graphics devices. More specifically, the system will satisfy all the general purpose graphics requirements for the SACC user community.

The system will be based on the SIGGRAPH Core Standard graphics package TEMPLATE. This package provides the flexibility previously unavailable at the SACC facility by providing software which is machine independent, device independent, and supports color and interactive analyses.

Significant FY83 accomplishments include integration of the world map data bases, along with the design of the scientist-friendly interface, which will allow the user to focus on the science at hand instead of programming details.

FY84 plans call for implementation and test of this design.

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NETWORK SYSTEMS

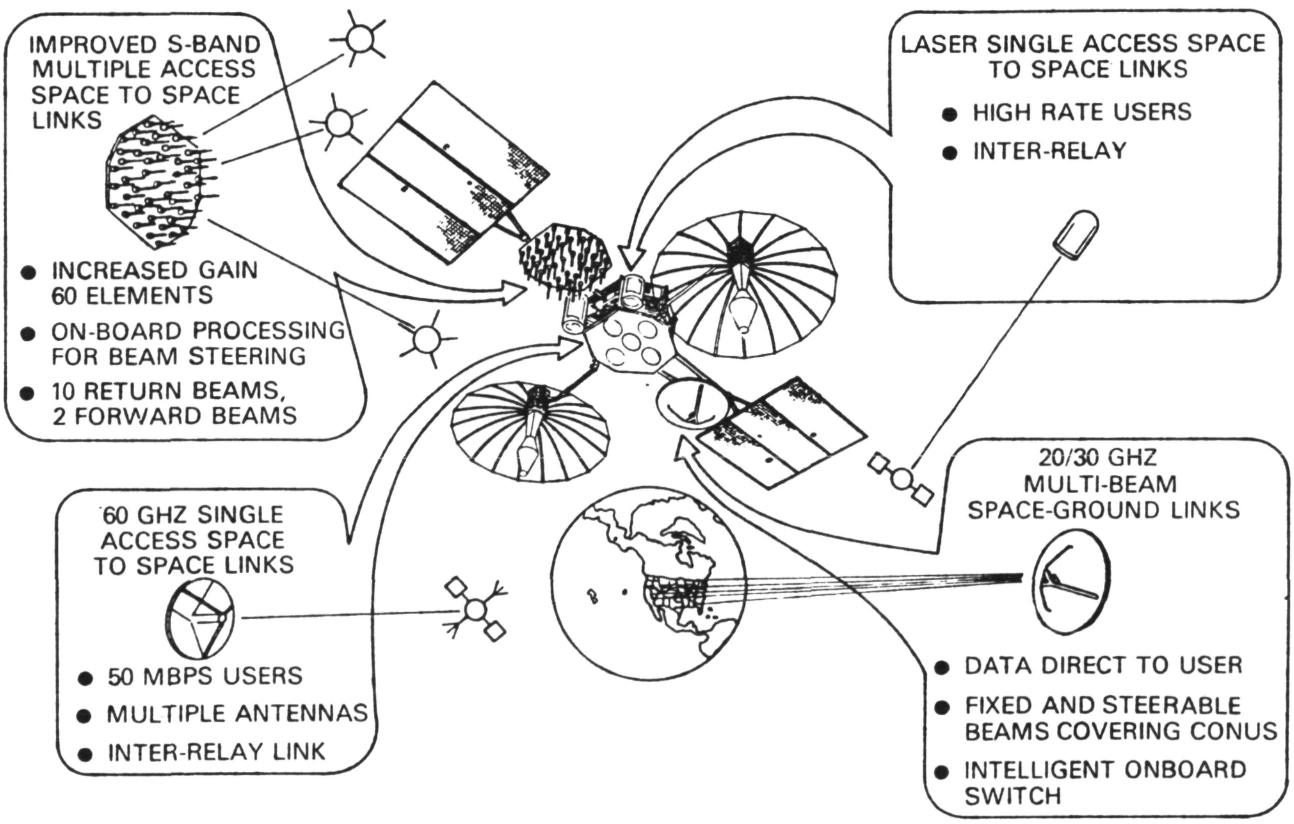
Tracking and Data Acquisition System for 1990's

A study to define a baseline Tracking and Data Acquisition System (TDAS) architecture that will satisfy NASA's requirements in the 1990's and maintain the Tracking and Data Relay Satellite (TDRS) services was completed in July. The study began by defining mission profiles for both NASA and DOD users of TDAS. The mission profiles were descriptions of the missions (experiment, orbits, timeframe) and summarized user communications requirements (dump rate, contact time, navigation accuracy).

Based upon these requirements, a communications model was specified, and the space segment, ground segment, and navigation system architectures were developed. Needed technologies, for both TDAS and users, were identified and assessed. The key technologies identified were laser and 60-GHz single-access space-to-space links, 20/30-GHz multibeam space-to-ground links, and an improved S-band multiple access system. These technologies are shown in the figure.

Alternative control and operations concepts were explored. The operational impacts of the new TDAS services were assessed, as well as the use of new navigation techniques in the TDAS timeframe.

The key findings of the study were far reaching. By the mid-1990's, NASA requirements for single-access channels will exceed TDRSS capacity by a substantial margin. The TDRSS has four single-access channels, but NASA will require at least ten to support its missions with a channel availability of 90 percent or better. With new technology, a 2-TDAS spacecraft constellation will satisfy NASA requirements. The TDAS will allow users direct access to



Technologies needed for operational data acquisition and navigation support to users in the mid to late 1990's are shown. Except for the laser links, these technologies are all considered low to medium risk for readiness by 1989, the cutoff date for TDAS technology.

their spacecraft and payloads and eliminate the need for high-cost DOMSAT relays. The baseline TDAS spacecraft can be developed with moderate risk technology, with a 5- to 10-percent increase in weight over the TDRS spacecraft, and with about 1300 watts of additional power.

In the TDAS timeframe, beacon one-way tracking will satisfy users in the TDAS mission model with accuracy requirements down to 10 meters. One-way tracking eliminates much of the operational complexity of coordinating forward and return links required of two-way tracking.

Now that a baseline architecture has been developed, it will be used to define goals and objectives for the next phase of TDAS technology and system studies. By 1986 these studies should make clear, both from requirements and technology perspectives, the direction NASA should take for the implementation of a follow-on system.

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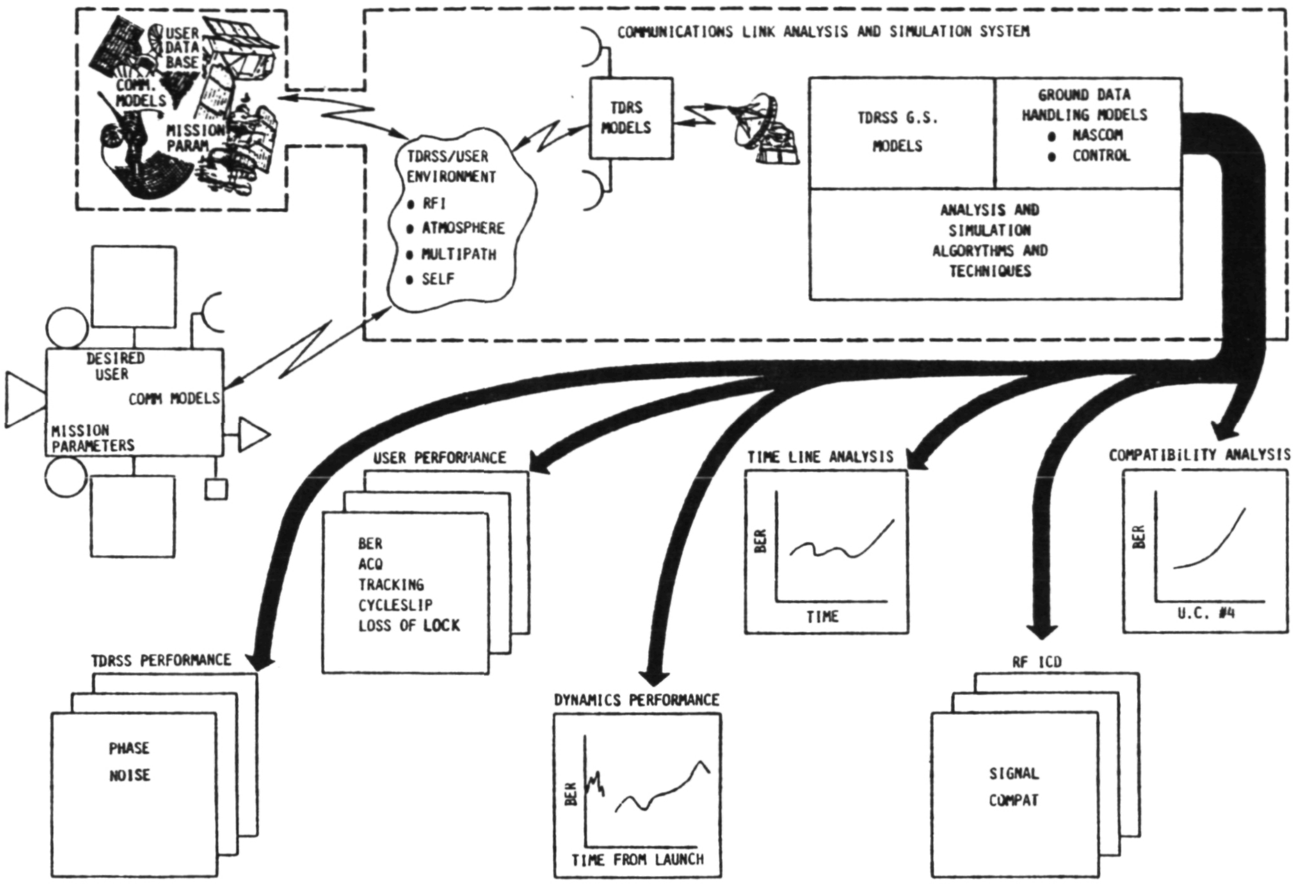
Sponsor: Office of Space Tracking and Data Systems

The Communication Link Analysis and Simulation System

The TDRSS, which will be the primary spaceflight communications and tracking support element of the NASA Networks, is a threshold communications system where normal operating margins are expected, and in some cases encouraged, to be small. This results in a communications or tracking link where maximum efficiency must be used, where signal distortions must be minimized, where all channel environment parameters must be considered, and where accurate, thorough and rapid analysis of all appropriate performance parameters must be conducted. The classical communications system analysis techniques in use cannot provide the analysis capabilities and accuracies required, they cannot consider simultaneously all of the significant parameters and cannot consider the non-Gaussian communications channel environment of the TDRSS. These classic techniques also cannot provide the rapid analysis capability needed by the Networks to ensure performance and compatibility of the User/TDRSS interface in a dynamic analysis environment.

The solution to this problem is the development of the CLASS system which can provide all necessary analyses in the required timeframe and to the required accuracy. The CLASS also permits many of the analyses to be performed by personnel who are not experts in the area of communications system analysis, thereby reducing the demand on this limited resource. This user can for example, by inputting a description of the TDRSS user data system, transmitter and antenna systems, perform an analysis to determine the bit error rate of the data at the output of the TDRSS. This analysis can consider simultaneously the users specific link parameters, all signal distortion parameters, antenna characteristics, user vehicle dynamics, the impact of RFI, multipath, atmospherics and TDRSS hardware and software characteristics. This analysis can be performed for all TDRSS compatible signal configurations, both forward (command) and return (telemetry). The CLASS models all elements of the communications link from the point at which the data are generated to the point at which the data are utilized. A pictorial representation of the capabilities of the CLASS system is shown in the figure.

The primary performance parameters which can be analyzed by the CLASS are data/symbol bit error rate, data/symbol slippage statistics, cycle slippage statistics, signal/data acquisition statistics, loss of lock probabilities, tracking data accuracies, false lock statistics, system interference, and autotrack system performance. These parameters can be analyzed on an end-to-end system basis or on a system-by-system basis. They can be performed as a single point analysis for a single value of each variable, on a sensitivity basis where the performance parameter is computed against the variation of one or more variables or the evaluation can be on a timeline basis where the performance parameters are evaluated against a mission timeline. These parameters can be used to evaluate the performance capabilities of the TDRSS User link or to evaluate the performance of the TDRSS system or any component of the system.



Communications Link Analysis and Simulation System capabilities.

The CLASS system is configured to provide conversational, self-prompting inputs and outputs in an effort to simplify the operation of a very complex analysis system and to ensure that the results derived at each level are correct and reliable. The system itself is currently being validated and will be fully validated when complete to ensure the accuracy of the analysis techniques and models. The system is operated under a central control system which links the appropriate analysis/simulation modules to provide the required analysis.

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Sponsor: Office of Space Tracking and Data Systems

Second Generation Tracking and Data Relay Satellite User Transponder

Spacecraft radio frequency transponders are continually undergoing changes as new requirements become known and new developments in technology become available. A major development of the late "70's" was the NASA Standard Tracking and Data Relay Satellite System (TDRSS) User Transponder. This transponder, the spacecraft terminal of the TDRSS, was also fully compatible with the ground station facilities of the NASA Spaceflight Tracking and Data Network (STDN). Designed for both Multiple Access (MA) service for S-band Single Access (SSA) service requirements of the TDRSS, this unit represented a major technological advance in transponder design.

Technology in the electronics field is continually changing and by 1980 components in the transponder using beam lead fabrication techniques as

well as the processes for the Large Scale Integration (LSI) circuits were obsolete. It was found that several characteristics of the transponder did not fully meet the requirements of the TDRSS User Constraints that were published in January 1980. Looking ahead, as the TDRSS Network became operational and the STDN was no longer available, the full STDN capability of the transponder would no longer be required. Also, new requirements were becoming known such as onboard navigation for future spacecraft missions and the Electronic Switching Spherical Antenna (ESSA) which require interfaces with the transponder. Indications were clear that a major redesign was required.

All of the above factors were combined into a program sponsored by the Advanced Systems Office, Office of Spaceflight Tracking and Data Systems, NASA Headquarters, resulting in the Second Generation TDRSS User Transponder. The new design, started in January 1982, will replace the obsolete parts, improve the characteristics for full compliance with TDRSS User Constraints, provide options that generate Doppler information for onboard navigation and the interfaces for the ESSA, and retains a minimal capability (there is no ranging channel) for back-up communications with a ground station. A special feature of the new design is the inclusion of a numerically controlled oscillator which provides the capability to make corrections of the transponder frequency through the command system.

The program provides for an engineering model available by April 1984 and a qualified prototype unit by April 1985. A follow on program will develop flight transponders for the Gamma Ray Observatory and Cosmic Background Explorer spacecraft with delivery expected in early 1986.

Specifications, published as STDN No. 203.8 "Performance and Design Requirements Specification for the Second Generation TDRSS User Transponder" dated August 1983, reflect the status of the design through the Preliminary Design Review, held in April 1983, and will be finalized after the Critical Design Review now scheduled for April 1984.

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Sponsor: Office of Space Tracking and Data Systems

MISSION AND DATA OPERATIONS

Mission Operations

GSFC has the responsibility for mission operations for many near-Earth flight programs. As control center operations become more automated, the human interface to the operation needs to be considered. Ongoing work is defining and prototyping the interface and configuring support in an automated command and control environment. Use of color displays and interactive touch sensitive display panels are being studied. Advances in technology are also allowing for the interconnection of remotely located computational elements which geographically distribute the control center functions. The GSFC study effort will address new possibilities for distributing functions, the application of new technology, and operational considerations for Space Shuttle payloads.

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Sponsor: Office of Space Tracking and Data Systems

High Volume Data Processing

Future GSFC data processing facilities will require large data storage with rapid access to any data file. Individual storage media will need to be transportable to other processing locations and be relatively inexpensive. The GSFC is supporting the

development of computer-compatible digital optical disk recorder/reproducers. These devices use laser light to record more than 10 billion bits of data on a single surface of a 14-inch diameter disk coated with a thin layer of optically sensitive material. In 1983, a detailed systems design with emphasis on an intelligent optical disk controller was completed with implementation commencing in 1984.

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Sponsor: Office of Space Tracking and Data Systems

Attitude/Orbit Technology

Orbit and attitude computations have traditionally been performed on larger computers primarily due to requirements for a large data base and complex computations. Recent computer technology advances have enabled these computations to be performed in distributed mini and microcomputers.

Data processing techniques and breadboard orbit and attitude systems have been developed which may be placed on board spacecraft or at distributed ground locations such as the control centers. During 1983, testing of breadboard microprocessor-based orbit and attitude systems has shown very promising results with regard to evaluations of timing, accuracy, and applicability.

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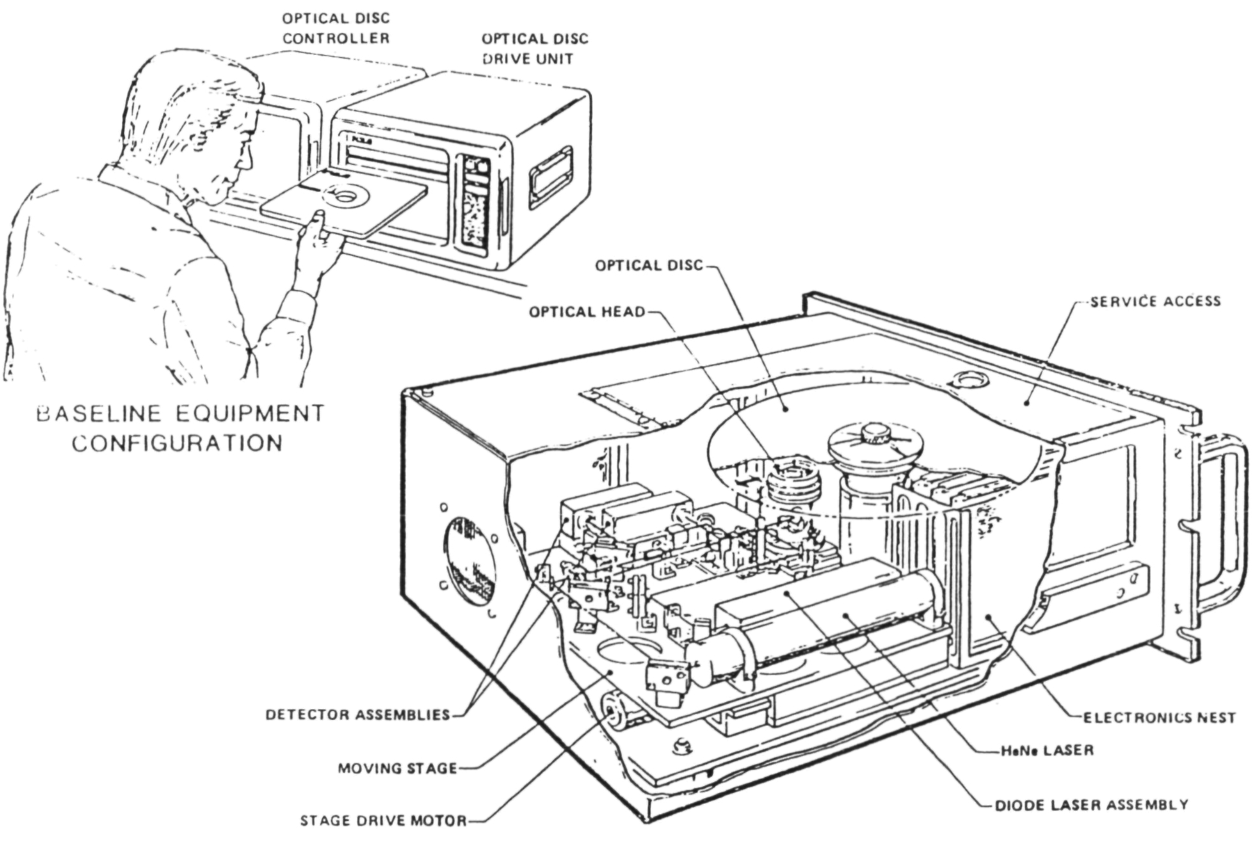
Sponsor: Office of Space Tracking and Data Systems



Conceptual drawing of demonstration of optical disk system.

Software Engineering

During the past year, efforts continued toward the study, evaluation, and enhancement of software development techniques within the Goddard Software Engineering Laboratory (SEL). Based on measurements of the software development process, practical experience and empirical studies, the SEL produced several documents which will be utilized for future software development in the flight dynamics area. These include a "Software Manager's Handbook," a "Guide to Software Cost Estimation," and "Measures and Metrics for Software Development." A Flight Dynamics Analysis System was completed this year utilizing the technology of rapid prototyping. A detailed study of the prototype, initiated during the year, will provide guidelines and insight into the application of prototyping as a software methodology. The study is addressing what tools are required for rapid prototyping, when should rapid prototyping be applied, and what are meaningful characteristics of a prototype.

Additional research efforts will continue during the upcoming year to develop tools and measures applicable to the software requirements and design phases. Characteristics of software design as well as the software specifications will be evaluated to determine their impact on characteristics of the software end product.

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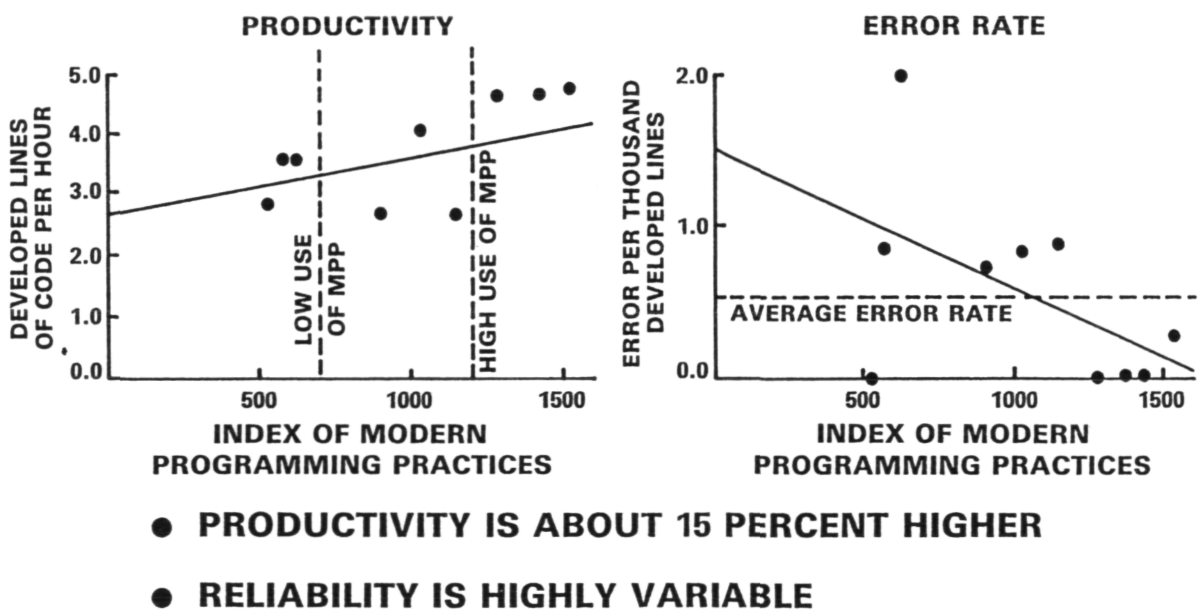
Sponsor: Office of Space Tracking and Data Systems

Human-to-Machine Interfaces

The two major objectives of the human-to-machine interface research activities are to (a) develop and apply "natural" human-to-machine interfaces for space payload and ground control systems and (b) develop a methodology and guidelines, emphasizing human factors issues, which will be used in the design and implementation of such interfaces. To support these objectives several thrusts have been identified. These are rapid prototyping techniques for programs; development of human-to-machine interface modeling mechanisms stressing human factors considerations pertinent for mission and data operations systems; and the implementation of a human factors laboratory to perform feasibility experiments, demonstrate interface concepts, and



Effects of modern programming practices on SEL software development.

establish cost and performance parameters for application-directed, near-term operational concepts earmarked for incorporation into mission and data operations systems. Based on a program rapid prototyping concept which incorporates a "three-window" architecture–one each for program text, input and output–an experimental system is under development. This system will serve as the first component of a testbed for fabrication and evaluation of rapid prototyping ideas.

Formal methods for capturing and modeling human-to-machine interfaces and interactions are under definition and development. Additionally, a philosophy and methodology for performing human factors analysis of systems is being developed. The continued development and transfer of human factors technology into the mission and data operations environment will provide a major improvement in human-to-machine interfaces.

Preliminary design and specification for a human factors laboratory was completed. This work addressed the physical requirements for the laboratory, management considerations, and a phased implementation. The human factors laboratory will provide the appropriate workbench environment to support the research and development efforts needed to facilitate the implementation of advanced human-to-machine interfaces for near-term application in the mission and data operations environment.

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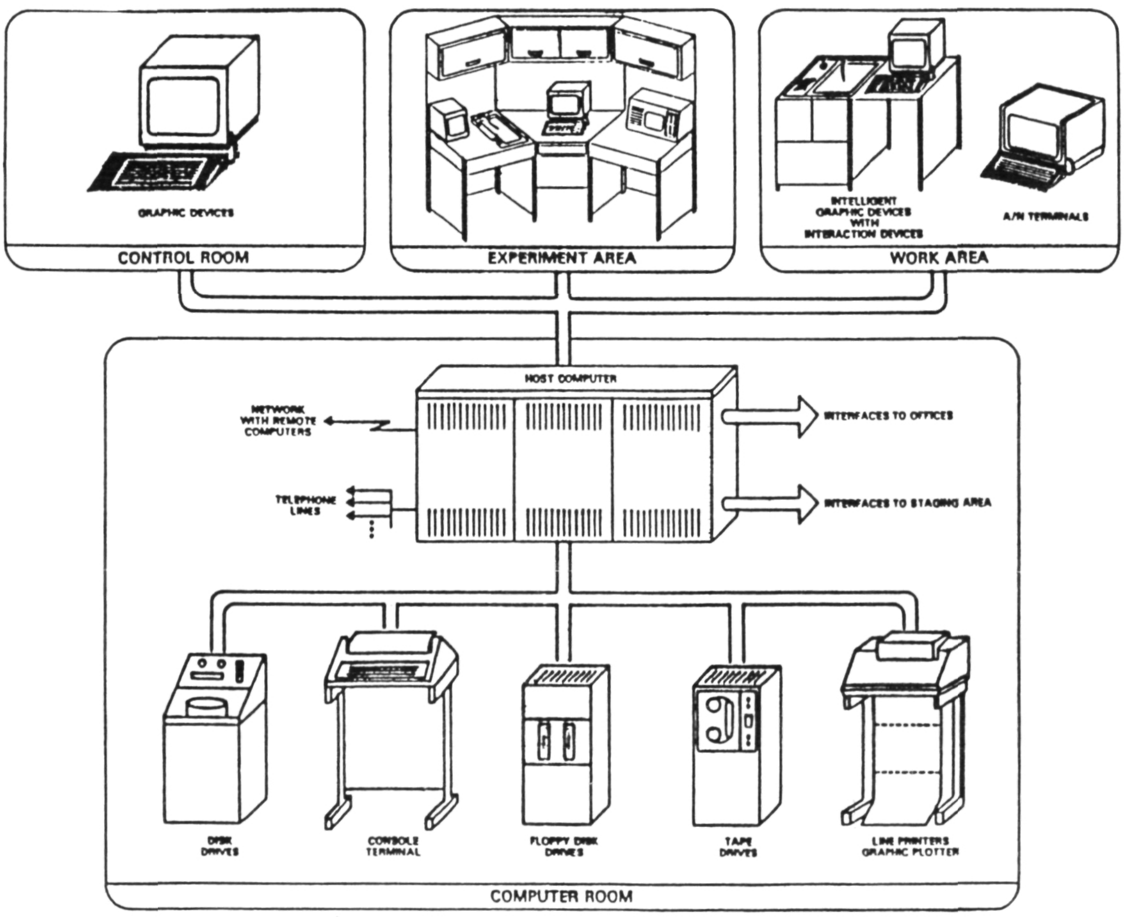
Sponsor: Office of Space Tracking and Data Systems



Human-to-machine interface technology.

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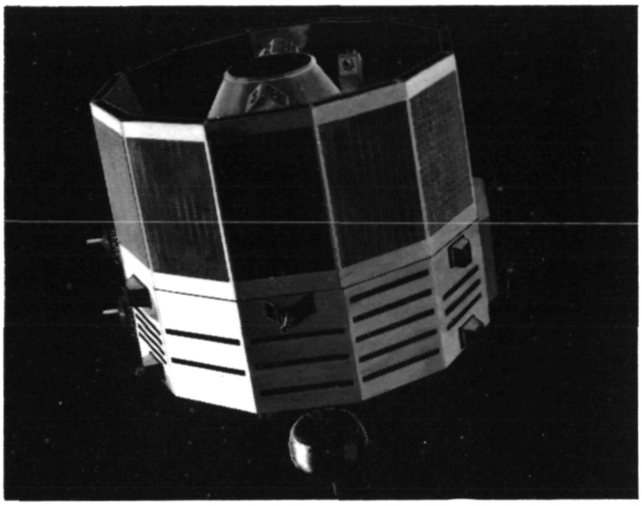
FLIGHT PROJECTS AND MISSION DEFINITION STUDIES



During FY 1983, scientists and engineers at the GSFC have been involved in planning and development of a number of new satellite programs and the redirection or repair of two orbiting spacecraft to obtain maximum use of space data.

Search and Rescue Satellite-Aided Tracking Mission

During Fiscal Year 1983 the Search and Rescue Satellite-Aided Tracking (SARSAT) Mission of the Metsat Project has successfully demonstrated satellite-aided search and rescue with three spacecraft. Since the initial application of the SARSAT system in September 1982 there have been 86 lives saved where the satellite data were used to assist in the rescue. A series of system tests was conducted with all three spacecraft which demonstrated that the system meets or exceeds specifications in all areas. The first spacecraft capability, the Soviet COSPAS-1 satellite, was launched in June 1982 and made available to the SARSAT Project in September 1982. The second Soviet satellite, COSPAS-2 and the U.S., Canada, France SARSAT systems were launched in March 1983. The SARSAT system was launched on board NOAA's NOAA-8 operational environmental satellite. Currently all three satellites are being used by the U.S. Air Force and the U.S. Coast Guard to assist in real world rescue operations using the 121.5/243 MHz Emergency Locator Transmitters (ELT's) employed by the aeronautical community and the Emergency Position Indicating Radio Beacons (EPIRB's) employed in the maritime community. In addition, the Search and Rescue agencies are conducting detailed tests and demonstrations using experimental 406 MHz ELT's and EPIRB's developed for the SARSAT program. These tests and demonstrations are intended to demonstrate the added benefits to be gained by the 406 MHz system which allows a tenfold user capacity growth, more accurate location (5 km versus 20 km) user identification and distress information.

The SAR Mission of the Metsat Project at the GSFC is responsible for the U.S. portion of the SARSAT Project, an international cooperative project involving the U.S., Canada, and France. NASA is the system manager of the U.S. participation which includes NOAA, DOT, and DOD. Canada provides the spaceborne repeater for relay of the 121.5 and 234 MHz signals from ELT's carried by approximately 200,000 U.S. aircraft and EPIRB's carried by more than 2000 ships. Canada also provides a repeater for experimental beacons operating at 406 MHz. France provides a spaceborne processor for the 406 MHz experimental beacons. The U.S.

integrates these two instruments on board the Tiros Series of NOAA environmental satellites. Each country provides its own Local User Terminals (LUT's) and test beacons as well as strong participation by the SAR users in the demonstration of the system. The location of the ELT's and EPIRB's is accomplished with the same Doppler location principal demonstrated by satellite data collection systems such as the Nimbus RAMS and the ARGOS system. The Soviet Union cooperates with the SARSAT partners by making its own SAR satellite system, COSPAS, interoperable with the SARSAT system. The SARSAT equipment will also be carried by NOAA-F, -G, -H, -I, and -J to be launched during the remainder of this decade. GOES-G and -H will perform 406 MHz SARSAT experiments from geosynchronous altitude.

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Sponsor: Office of Space Science and Applications

Solar Maximum Repair Mission (SMRM)

In August 1982, Congress gave NASA approval to conduct rendezvous and repair/retrieval of the Solar Maximum Mission (SMM) Observatory after more than 4 years of in-orbit operation using the Space Transportation System (STS) and the Multimission Modular Spacecraft (MMS) Flight Support System (FSS). The mission is currently manifested with the Long Duration Exposure Facility (LDEF) for STS-13 on April 4, 1984.

The objective of the SMRM is to return the SMM Observatory to operational status and to determine the STS capability to retrieve and repair the spacecraft in orbit. However, in the event the planned repairs are not effective, the entire observatory will be returned from orbit in the FSS.

The pointing repair will be achieved by in-orbit replacement of the MMS ACS Module with a Landsat-D/SMM flight spare. This capability is provided by the modular design of the MMS spacecraft which was the first application of this technique for free-flyer/STS interface compatibility. Replacement of the ACS Module by Extravehicular Activity (EVA) will restore full scientific operation to six out of seven instruments in the SMM payload.

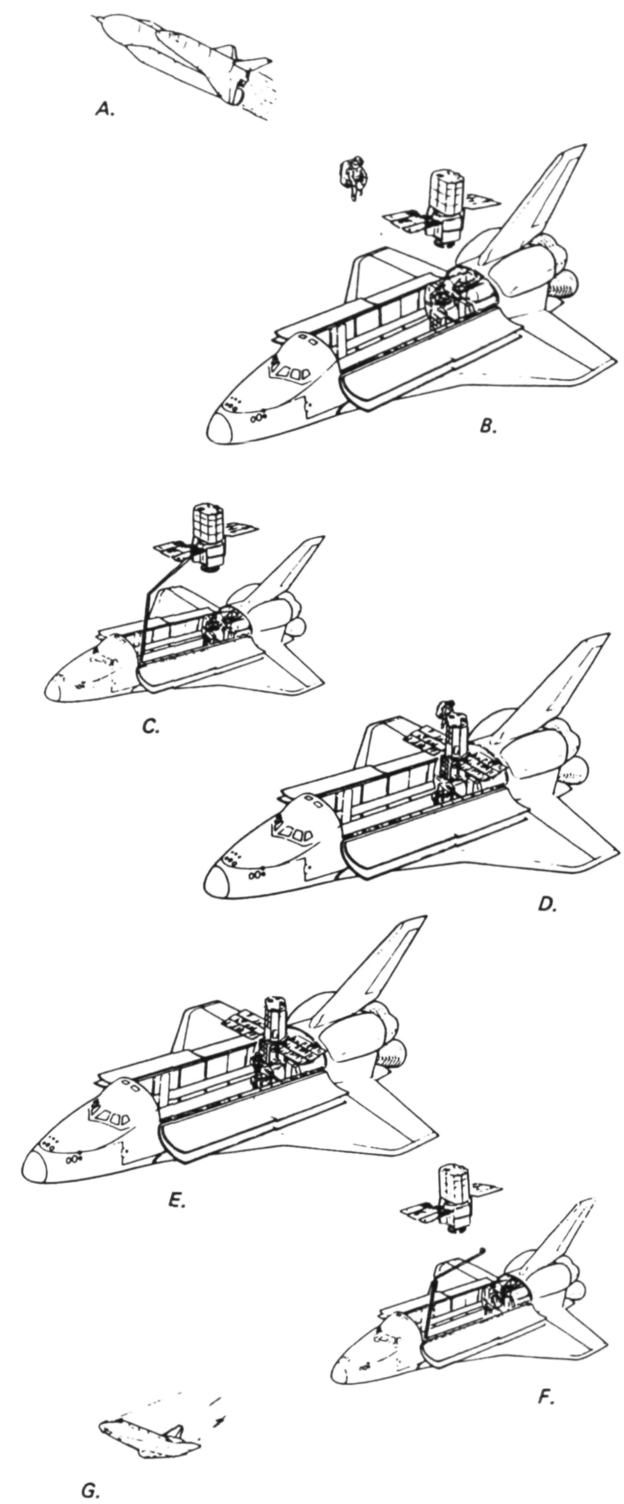
The elimination of operating instrument anomalies is planned by EVA installation of a plasma baffle over the Soft X-ray Polychromator (XRP) propane bleed port, and replacement of the failed Coronagraph/Polarimeter (C/P) Main Electronics Box (MEB). Except for the HXIS instrument failure which will not be repaired, the SMM Observatory will be returned to full operation.

Before the ACS on SMM malfunctioned, the mission had been declared a scientific success. Unique observations of solar flares had been made. A number of these observations have provided new insights into the physics of flares.

As impressive as the SMM results have been, one must realize that the investigators were still not using the full observing power of the mission when the ACS malfunctioned. This untapped potential should be fully realizable with the renewed mission that will result from the repair activity. Following activation of the Tracking and Data Relay Satellite System (TDRSS), the repaired SMM will be capable of supplying high quality recorded and near real-time solar observations on sunside passes. This will give investigators unprecedented capabilities for immediate participation in the conduct of their experiments.

The hiatus, between the first phase of the mission and that which will result from the repair activity, offers two major advantages to the scientific community. First, detailed understanding of the early SMM results will spur the generation of highly refined and well-focused observing programs for the renewed mission. Second, considering the period in the solar cycle, the payload will be able to pursue several interesting quiet-Sun scientific objectives. Among these will be the investigation of coronal holes, monitoring of solar constant as the cycle approaches minimum and the monitoring of the evolution of the solar corona during the minimum period.

The SMRM is the first practical demonstration of the STS capability to rendezvous and service a free-flyer satellite. Numerous missions, such as Landsat-4,



The Solar Maximum Mission (SMM) repair sequence of events: a) launch from Kennedy Space Center; b) rendezvous, MMU capture, and altitude stabilization; c) RMS grapple; d) SMM berthing and XRP Experiment update; e) SMM ACS module exchange and C/PMEB replacement; f) HGAS deployment and SMM redeployment; and g) deorbit and landing at Kennedy Space Center.

Landsat-D′ (LSD), Long Duration Exposure Facility (LDEF), Upper Atmosphere Research Satellite (UARS), Gamma-Ray Observatory (GRO), Advanced X-ray Astrophysics Facility (AXAF), the Space Telescope (ST), and Leasecraft have baselined, or are considering retrieval and/or servicing for the purpose of refurbishment, reuse, and updating of the spacecraft and payloads.

After the landing, an assessment of long-term space environmental effects on the recovered hardware will be performed and the SMM ACS Module will be reworked to support the requirements of the LSD Program. The magnitude of the rework and associated cost of refurbishment will help establish guidelines in planning future reuse of free-flyer spacecraft components and the FSS by other missions. The lessons learned in the course of this mission and in postlanding analyses will help generate improved techniques for the design of future Shuttle compatible spacecraft.

The SMRM is planned as a five-man 6-day operation with the STS dropping its external tanks into the Pacific Ocean as the Orbiter ascends close to the SMM operational orbit by direct injection. The LDEF deployment will be at about 473 km (255 nm) and STS rendezvous with the SMM Observatory will be at an altitude of about 500 ± 37 km (270 ± 10 nm) and inclination of 28.5°. The Orbiter will carry a crew of five and a repair cargo consisting of the full FSS employing Cradles, A, B, and A′ and its avionics, a replacement MMS ACS Module, MEB and XRP experiment repair kits, two Module Service Tools (MST's), two Extravehicular Maneuvering Units (EMU's), Portable Foot Restraints, Manipulator Foot Restraints on the end of the Remote Manipulator System (RMS), two Manned Maneuvering Units (MMU's), and two powered screwdrivers.

Phasing of the STS launch window and subsequent STS OMS burns are such that the Orbiter will rendezvous and station keep at a safe distance of about 90 m (300 feet) from the SMM. An astronaut will approach the SMM by untethered flight using an MMU equipped with special trunnion grapples to capture and stabilize the SMM. The Orbiter will then maneuver to within about 9 m (30 feet) of the SMM, where the 15 m (50 feet) long RMS will capture the Observatory at the temporary grapple. The RMS will then berth the SMM to the FSS in the

Shuttle payload bay, the MMS umbilical connectors will be remotely engaged, the spacecraft will be powered off and the batteries taken off line.

The untethered astronaut with the MMU will next maneuver to a location over one of the solar arrays to install a plasma deflection cover over the XRP propane exhaust port. He will then stow his MMU and join a companion to exchange the ACS module using Manipulator Foot Restraints on the RMS and Portable Foot Restraints and an MST. The crew will then reactivate the spacecraft from the Aft Flight Deck. A functional checkout of the SMM will be performed remotely from the GSFC SMM Project Operations Control Center (POCC) as the mission specialists rest. Following a day of rest for the astronauts, the final repair operation will be performed during a second EVA day which will consist of removing and replacing the MEB of the Coronagraph/Polarimeter and the panel on which it is mounted. This entails the removal and reinstallation of eleven "Cannon-D" type cable connectors. The same major EVA service aids will be used. This will conclude EVA activities.

If sufficient OMS propellant remains, the Orbiter will reboost the SMM to about 537 km (290 nm) altitude to provide for extended operations.

Following the deployment of the High Gain Antenna System for use with the TDRSS, a final observatory functional check will be made and the RMS then used to release the observatory to orbit. The Orbiter will then back away from the SMM, prepare for deorbit, deorbit, and land at KSC.

After landing, the failed Coronagraph/Polarimeter MEB, the FSS, and retrieved ACS Module will be removed from the Orbiter, and transported to a hangar for inspection. The ACS Module will then be returned to the Module Contractor for inspection, refurbishment, and retesting as a Landsat-D spare. This will allow the first hands-on detailed engineering assessment of the effects of extended spaceflight on satellite hardware. The FSS will be brought back to the GSFC, updated for the ST Mission, then placed in storage until required for future missions.

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Sponsor: Office of Space Science and Applications

Space Telescope

The objective of the Space Telescope (ST) Program is to establish and operate an astronomical facility consisting of an orbiting observatory and a ground system which will greatly exceed the capability of even the best ground-based observatory, and to make it available for research in optical astronomy by scientists from the United States and abroad.

The Goddard Space Flight Center (GSFC) is responsible for the science and operations aspects of the ST. Specifically, the ST Project at the GSFC is responsible for managing the following:

- Design and development of the five Scientific Instruments (SI's) for use on the first of the ST;
- Design and development of the SI Control and Data Handling (SI C&DH) system;
- Verification and Acceptance Program (VAP) to integrate and test the SI's and the SI C&DH;
- System engineering of the total ground systems;
- Design and development of the Science Operations Ground System (SOGS);
- Establishment and operation of the ST Science Institute (ST ScI), located on the Johns Hopkins University campus in Baltimore, Maryland (officially opened on June 15, 1983), will conduct the science operations; and
- Operation of the total observatory.

In addition, the GSFC Mission and Data Operations Directorate is responsible for the design, development and maintenance of the Data Capture Facility, the Payload Operations Control Center, and

other institutional support, jointly called the ST Observatory Management System.

The European Space Agency is providing the ST solar array, one scientific instrument, and participation in science operations.

During Fiscal Year 1983 significant progress has been made in developing and integrating the flight instruments for the ST. The SI C&DH which provides the command and data interface for the five instruments was environmentally and acceptance tested at Fairchild Industries, Gaithersburg, Maryland. This system which includes the NASA Standard Flight Computer (NSSC-1) dedicated to instrument control and data processing was delivered to the GSFC in April of this year. Engineers at Goddard integrated this equipment into the VAP ground equipment to ensure readiness for delivery of the first flight instruments—the High Speed Photometer (HSP) designed and developed by the University of Wisconsin. When delivered, the HSP was passed through receiving and inspection, given an incoming performance test, and integrated into the VAP. From that point both the short- and long-term functional tests were conducted interfacing the HSP through the SI C&DH to the ground test system.

Since that first set of major equipment deliveries, three additional instruments have been acceptance tested and brought to Goddard for integration into the VAP. These instruments include:

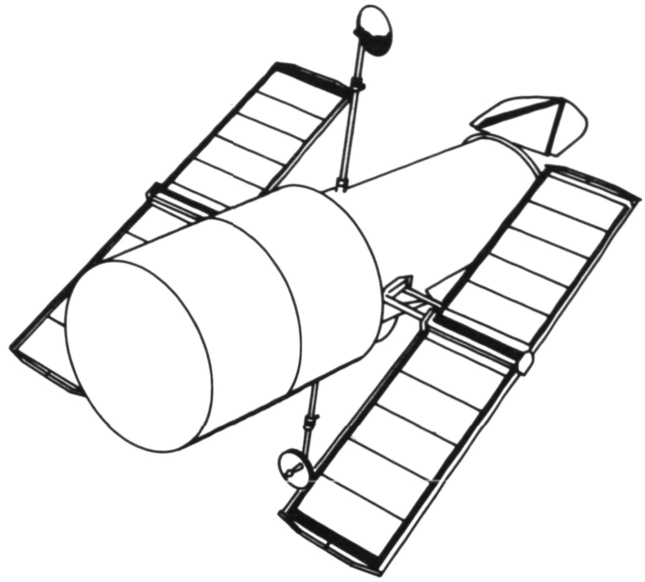
- High Resolution Spectrograph (HRS) designed and developed for Goddard by Ball Aerospace

- Wide Field Planetary Camera (WF/PC) designed and developed by JPL for CALTECH

- Faint Object Spectrograph (FOS) designed and developed by Martin Marietta for the University of California San Diego

A fifth instrument not yet delivered is the Faint Object Camera (FOC) which is provided by the European Space Agency (ESA). Delivery of this instrument is currently planned for late November of this year.

In addition to electrical and performance testing of instruments, VAP provides an excellent test bed for the acceptance of the NSSC-1 flight software



Space Telescope Observatory.

which controls instrument status and provides some onboard data processing. The flight software is being developed by IBM, Gaithersburg, Maryland. Plans for VAP testing in the first quarter of Calendar Year 1984 include multiinstrument system testing, which will demonstrate performance capabilities with two or more instruments operating simultaneously under NSSC-1 control.

The ST Operations Control Center (STOCC) is the facility used for controlling the ST when it is placed into Earth orbit in 1986. This facility was completed in 1983 and computers and operator's consoles are now being installed and tested. The STOCC is located at Goddard Space Flight Center and is operated by Lockheed Missiles and Space Company.

The ST Science Institute has been created to administer the ST science research program for NASA and to plan and conduct the actual ST science observations. The ST Science Institute is operated by the Association of Universities for Research in Astronomy under contract to NASA. A guide star selection system is under development that will specify the coordinates of suitable stars sharing the telescope field of view for each observation made by the ST. Guide stars are used by the ST Fine Guidance Sensors to stabilize the pointing of the telescope during observations. A star catalog is now being created by

optically scanning sky survey plates and precisely measuring the coordinates and magnitudes of light sources recorded on the plates. This catalog will be substantially larger than other catalogs now in use because of ST's ability and need to track on fainter objects than existing catalogs include.

The SOGS, a complex network of computers and image processing terminals, is now being developed by TRW under contract to NASA. This system will schedule observations to be made by ST and to process the resulting data and produce products which are useful to astronomers. The hardware parts of the system are being assembled, and computer programs are being written that will enable the system to perform its needed functions. The SOGS will be delivered to the ST Science Institute in 1984 and will then be subjected to extensive operational testing prior to the launch of ST.

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Sponsor: Office of Space Science and Applications

Cosmic Background Explorer

The Cosmic Background Explorer (COBE) is the first satellite designed specifically for cosmological studies. It will measure diffuse radiations, which can be detected from much greater distances than discrete objects.

The COBE mission plan is to make a definitive exploration and study of the diffuse radiation of the Universe between the wavelengths of 1 micrometer and 9.6 millimeters by means of three scientific instruments: a Differential Microwave Radiometer (DMR) system and two cryogenically cooled infrared instruments, Far Infrared Absolute Spectrometer (FIRAS) and Diffuse Infrared Background Experiment (DIRBE). The DMR detects and maps anisotropies on an angular scale of 7 degrees and larger in the cosmic background radiation at 3 frequencies: 31.5, 53, and 90 GHz (9.5, 5.7, and 3.3 mm). The FIRAS measures the spectrum of the 3°K cosmic background radiation, the interstellar dust emission, and any unknown sources in the wavelength range from 100 micrometers to 1 centimeter. The DIRBE is a 10-band filter photometer covering the wavelength range from 1 to 300 micrometers. Its purpose is to detect extragalactic background radiation and to measure the foreground sources such as starlight, the zodiacal light, and the thermal emission from interplanetary and galactic dust.

The COBE instruments will be operated in a survey mode and the science and ancillary data will be time-division multiplexed to form a single data stream. This data will be recorded continuously on board the observatory and transmitted directly to a ground receiving station once each day. The Tracking and Data Relay Satellite System (TDRSS) will be used to support the mission from launch through Shuttle separation, and a multiple access TDRSS S-band link will be used to provide tracking, command, and real-time telemetry capability throughout the mission lifetime. The operation and control functions will be provided using one of the GSFC Multi-Satellite Operational Control Centers. A COBE Science Data Room will be used to provide each of the experimenters with direct access to all of the observatory data (ancillary and science) for the purpose of data reduction, analysis, and experiment mission planning.

Significant progress occurred during FY83 for the COBE instruments. For the DMR, a thermal design change to cool two of the three radiometers to approximately 150°K was instituted; this will result in an increase in sensitivity of a factor of two or more. In addition, breadboard tests of the radiometers were run to confirm design concepts. For the FIRAS, the mechanical, optical, and thermal designs of the spectrometer were completed and construction of flight hardware initiated. For the DIRBE, the thermal, optical, and the majority of the mechanical designs were completed and construction of the flight hardware initiated. Other FY83 developments for the instruments included:

- Initiation of the construction of the flight structure which interfaces the FIRAS and DIRBE instruments with the flight dewar.

- Award of a contract for construction of a large subcooled liquid helium dewar which will be used to functionally test the FIRAS and DIRBE instruments at temperatures less than 2°K.

COBE, including the scientific instruments, will be handled in the in-house subsystem procurement mode at the NASA/Goddard Space Flight Center.

COBE, a single observatory mission, will be launched from the Western Space and Missile Center (WSMC) by the Space Transportation System (STS) into a parking orbit of about 300 km, with a 99° inclination. COBE will then be placed into a 900-km altitude, Sun synchronous orbit by an integral hydrazine propulsion system.

A fourth quarter calendar 1987 launch is presently planned for COBE, followed by 1 year of flight operations and 2 years of data analyses.

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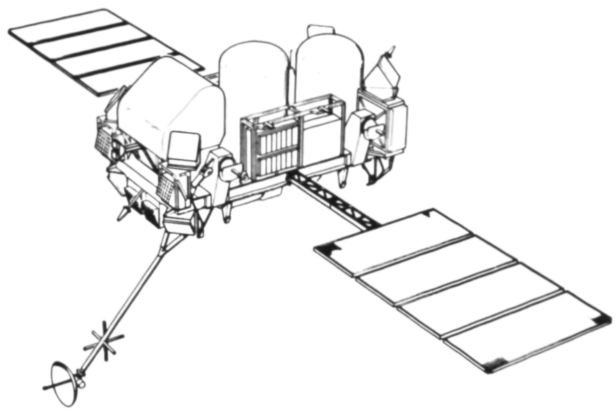
Sponsor: Office of Space Science and Applications

Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO) is one of the first large observatories to use the capabilities of the Space Transportation System (Shuttle). This 31,000-lb observatory is designed to study gamma-ray spectrums from the upper X-ray frequencies to 3×10^4 MeV region of gamma rays. In its 2-year mission the GRO will map the gamma-ray sources in the celestial sphere. The scientific instruments on GRO have sufficient sensitivity, resolution, and dynamic range to address the following crucial topics in astrophysics:

- Study of the dynamic evolutionary forces in compact objects such as neutron stars and black holes.
- A search for evidence of nucleosynthesis—the fundamental building process in nature—particularly in the environment of supernova.
- Study of gamma-ray emitting objects whose nature is not yet understood.
- Exploration of our galaxy in the gamma-ray range, especially with regard to regions difficult to observe at other wavelengths; the origin and dynamic pressure effects of the cosmic rays; and structural features, particularly related to high energy particles.



Gamma-Ray Observatory.

- Study of the nature of other galaxies in the energetic realm of gamma-rays, especially radio galaxies, Seyfert galaxies, BL Lacertae objects and quasars.
- Study of cosmological effects through the detailed examination of the diffuse radiation and the search for primordial black hole emission.
- Study of intense gamma-ray bursts of many types whose origins remain a mystery.

The mission contractor, TRW, has been under contract since February 1983. TRW is responsible for assuring that the overall mission of GRO is successful. TRW will build the spacecraft, integrate the science instruments, test, launch, and operate the observatory in orbit. The Fairchild Space Company (FSC) will furnish the communications and data handling module and MDAC will furnish the two power modules.

The four large instruments are to be furnished by government agencies. The Burst and Transient Source Experiment (BATSE) is being built by the Marshall Space Flight Center (MSFC), the Oriented Scintillation Spectrometer Experiment (OSSE) is

being built by the Naval Research Laboratory (NRL), the Energetic Gamma-Ray Experiment Telescope (EGRET) is being built by the Goddard Space Flight Center (GSFC), and the Imaging Compton Telescope (COMPTEL) is being built by the Max-Planck-Institute (MPI). All four instruments are in the final stages of design, and flight parts are in fabrication.

The GRO is planned to be flown in the latter part of 1988. The Observatory will be placed in a 400-km circular orbit at 28.5° inclination. Data from the Observatory will be transmitted via TDRS to the GSFC. The telemetered data are autonomous and will be distributed to the instrumenters for analysis within 48 hours.

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Sponsor: Office of Space Science and Applications

Deep Geotail Excursion with ISEE-3

During Fiscal Year 1983 the ISEE-3 has been moved from the forward libration point L_1 through a series of orbits in the Earth's tail in preparation for the transfer to encounter the comet Giacobinni-Zinner (in 1985).

The Geomagnetic Tail Excursion provides first *in situ* data on the geomagnetic tail configuration and dynamics in the unexplored region from beyond lunar orbit to the L_2 libration point (240 R_e) and first order information on the distant magnetopause, plasma mantle, B-Field dynamics, wave-particle interactions, and energetic particles. The science return will be vast in comparison with the limited knowledge available from Pioneers-7 and -8.

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Sponsor: Office of Space Science and Applications

Multimission Modular Spacecraft (MMS)

Following launch of the protoflight Multimission Modular Spacecraft (MMS) with the Solar Maximum Mission (SMM) payload on February 14, 1980, the first production MMS was successfully launched from the Western Space and Missile Center (WSMC) with the Landsat-D Thematic Mapper and Multispectral Scanner payload on July 16, 1982.

In addition to the usual three MMS modules, a new PM-1A Propulsion Module, providing 510 pounds of hydrazine, has successfully raised the satellite orbit from the planned Delta 3920 injection parameters to the operational orbit. In addition, orbit drag makeup burns have been made retaining the desired repetitive orbital ground track. This unit has sufficient propellant to permit Landsat-4 to operate for a number of years and then burn back to the Shuttle's parking orbit for possible retrieval and ground refurbishment.

The Landsat-D′ backup spacecraft was delivered from the Spacecraft Integration Contractor, Fairchild Space Company, to the Payload Integration Contractor, General Electric Company. The I&T effort was completed and the spacecraft and payload are being prepared for a backup mission that has become necessary since sets of cables, not designed for the day/night transitions of the Landsat-D orbit, have progressively lost power connections to the solar array panels. In addition, the wideband Ku-band telemetry has failed restricting the mission operations. The backup LSD′ mission is currently scheduled for March 1984.

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Sponsor: Office of Space Science and Applications

Flight Support System (FSS)

The Flight Support System (FSS), used for transporting to orbit and for in-orbit servicing and retrieving of the Multimission Modular Spacecraft

(MMS), has been completed and flight qualified for use. This system consists of three major subsystems: the spacecraft Retention Cradle A; stiffener and spacer Cradle B; and Cradle A′ with its Payload Berthing and Positioning Platform, and the FSS/Orbiter compatible avionics. These major configuration elements can now be operated independently or used collectively as a unified system in the STS Orbiter, depending upon the specific mission requirements.

The first application of the FSS will be the STS-13, Solar Maximum Repair Mission (SMRM), when the Space Shuttle and its crew will service and reboost or retrieve the SMM Observatory at an altitude of about 500 km (270 Nautical Miles) scheduled for April 1984.

Also planned is the use of the FSS Cradle A′ Berthing and Positioning System, and avionics for the servicing of the Space Telescope some 3 years following its launch.

Among the FSS applications under consideration are Landsat-D servicing or retrieval, and GRO, UARS, and AXAF operations.

The versatile FSS has been designed for use in up to 50 missions.

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Sponsor: Office of Space Science and Applications

Solar Optical Telescope

The Solar Optical Telescope (SOT) will conduct detailed observations of the solar disc in order to determine the densities, temperatures, magnetic fields, and nonthermal velocity fields in numerous solar features on the scale at which many basic physical processes are occurring. Recent observations show that the plasma in the solar chromosphere and transition region often exhibit a scale on the order of a few tenths of an arc second. Thus, to understand the flow of energy and mass on a global scale over the surface of the Sun, it is necessary to investigate structures only slightly larger than the photon mean-free-path of about 100 km.

The SOT Observatory consists of two major parts: the Telescope Facility, which remains essentially unchanged from mission to mission; and the Science Instruments (SI's), which, depending on the Science Objectives, may vary for each mission.

Two science instruments are to be flown on the first SOT mission. They are: the Coordinated Filtergraph Spectrograph which consists of a narrow band, visible tunable filtergraph, and a visible and ultraviolet spectrograph. The cameras for both systems use large CCD arrays. The instrument will study hydrodynamic and magnetic processes on spatial scales rarely, if ever, resolved from the ground. The instrument will have an active image motion stabilization system to enable diffraction-limited performance and a dedicated experiment processor for experiment control and data flow management. Near simultaneous visible and ultraviolet observations will follow the flows, energy, and magnetic fields continuously from the low photosphere into the corona; and the Photometric Filtergraph, consisting of a pair of high-speed film cameras behind broad pass band continuum filters. The Photometric Filtergraph will be combined with the Coordinated Filtergraph Spectrograph into one focal plane package for the SOT and the integrated instrument will be built by Lockheed Palo Alto Research Laboratory. The instrument will record high-resolution images of the solar atmosphere on photographic film. Filtergraphs will be recorded in the visible and as far down into the UV as practicable. The recorded data will be used to study granulation, surface flows, sunspots, and solar flares.

The SOT Observatory remains Shuttle-attached throughout the mission. It utilizes the Spacelab-provided Instrument Pointing System during in-orbit operations, and is mounted via launch locks directly to the Orbiter cargo bay during launch and landing. Mission operations are conducted by interactive control either from the Payload Specialist station in the Orbiter Aft Flight Deck or from ground-based stations in the Payload Operations Control Center.

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Sponsor: Office of Space Science and Applications

Upper Atmosphere Research Satellite Mission

The objectives of the Upper Atmosphere Research Satellite (UARS) Mission are to understand the mechanisms that control upper atmosphere structure and variability, assess man's impact on the Earth's ozone layer, assess the potential effect of stratospheric change on weather and climate, and develop an effective strategy for stratospheric monitoring.

Meeting these objectives requires coordinated measurements on a global scale of atmospheric chemistry, winds, and energy input. These data will be acquired by a single Observatory containing 11 scientific instruments and orbiting the Earth at an altitude of 600 km and an inclination of 57°. Since analysis of coordinated measurements is essential to the mission, a Central Data Handling Facility (CDHF) will be implemented at the GSFC for data processing and storage. Computer-based remote terminals will be located at each of the Principal Investigators facilities for communication with the CDHF and for performing data analysis.

During Fiscal Year 1983, definitions of the Observatory, the ground data processing system, and the flight operations support system were completed. Also, during this period, development of instruments progressed through the final definition phase which included completion of interface agreements, allocation of observatory resources, development of the overall instrument pointing error budgets, definition of the instrument mounting system, and implementation of breadboards and engineering models of selected segments of some instruments to reduce the risk in a number of high technology areas. Instrument Conceptual Design Reviews were started and programmatic agreements have been made with Principal Investigator institutions for implementation of the flight hardware.

Current project planning is based on launch of the Observatory in the fall of 1989 and 18 months of flight operations and 12 additional months of data processing and analysis.

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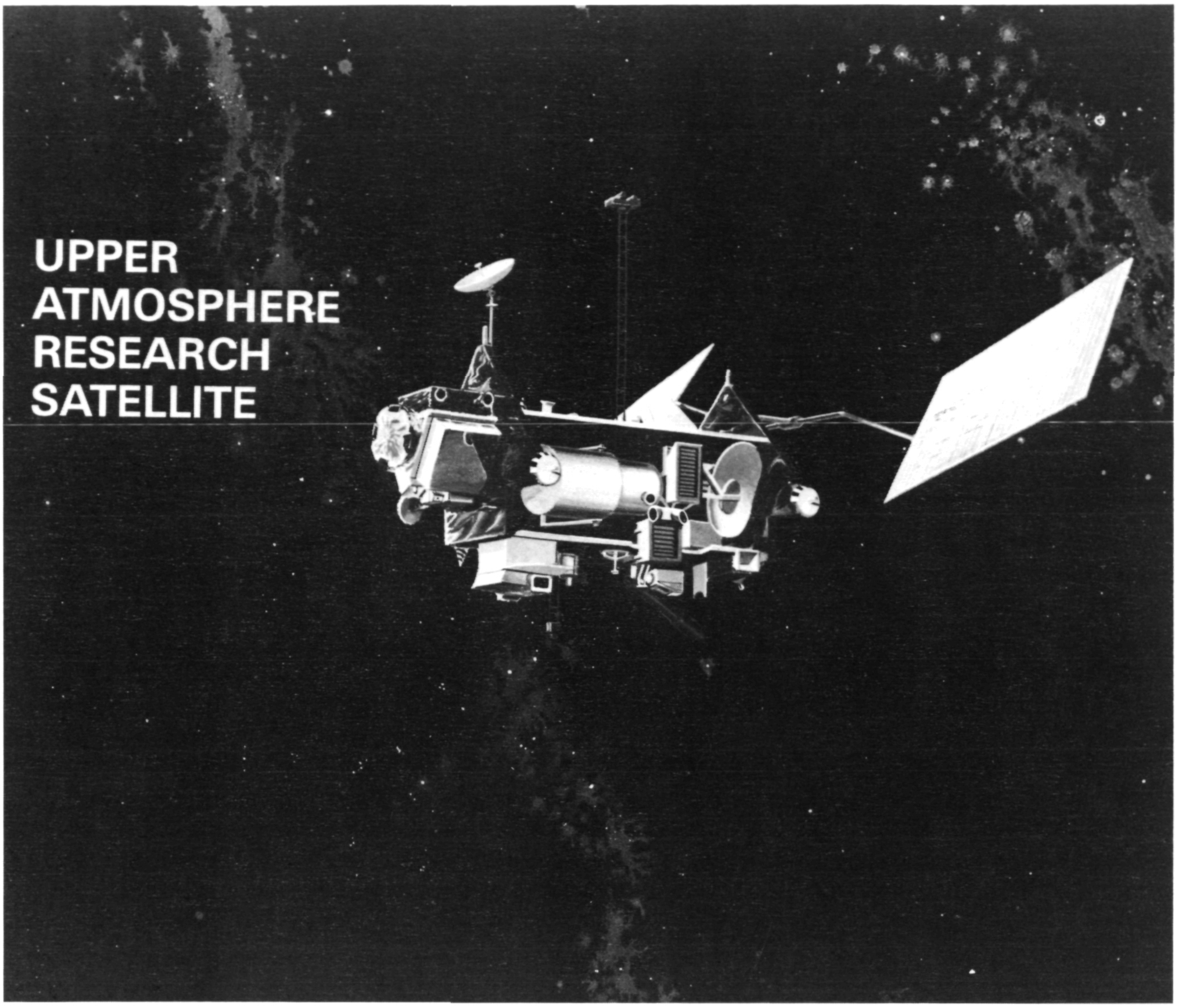
Sponsor: Office of Space Science and Applications


UPPER
ATMOSPHERE
RESEARCH
SATELLITE

ACRONYMS

ACS	Attitude Control System
AMU	Atomic Mass Unit
AOL	Airborne Oceanographic Lidar
APT	Automatically Programmed Tools
AVHRR	Advanced Very High Resolution Radiometer
AXAF	Advanced X-ray Astrophysics Facility
CAM	Computer-Aided Manufacturing
CLASS	Communication Link Analysis and Simulation System
COBE	Cosmic Background Explorer
COE	Corps of Engineers
COSMIC	Computer Software Management and Information Center
CZCS	Coastal Zone Color Scanner
DAVID	Distributed Access View Integrated Data Base
DBMS	Data Base Management System
DEC	Digital Equipment Corporation
DIRBE	Diffuse Infrared Background Explorer
DIS	Data Information System
DMR	Differential Microwave Radiometer
DMSP	Defense Meteorological Satellite Program
DOMSAT	Domestic Satellite
ELT	Emergency Locator Transmitter
EMU	Extravehicular Maneuvering Units
EPIRB	Emergency Position Indicating Radio Beacon
ERB	Earth Radiation Budget
ERRSAC	Eastern Regional Remote Sensing Applications Center
ESA	European Space Agency
ESSA	Electronic Switching Spherical Antenna
EUV	Extreme Ultraviolet
EVA	Extravehicular Activity
FEM	Finite Element Models
FIRAS	Far Infrared Absolute Spectrometer
FOC	Faint Object Camera
FOS	Faint Object Spectrograph
FSS	Flight Support System
FY	Fiscal Year
GEMPAK	General Meteorological Package
GMPTS	Ground Microwave Power Transmission System

GOES	Geostationary Operational Environmental Satellite
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center
HAPP	High Altitude Powered Platform
HCMM	Heat Capacity Mapping Mission
HCMOS	High Speed Complementary Metal Oxide Silicon
HRS	High Resolution Spectrograph
HSP	High Speed Photometer
IDSP	Interactive Digital Signal Processor
IFOV	Instantaneous Field of View
IMPATT	Impact Avalanche Transit Time
IMS	International Magnetospheric Study
IR	Infrared
IRAS	Infrared Astronomical Satellite
ISEE	International Sun Earth Explorer
IUE	International Ultraviolet Explorer
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LAPR II	Linear Array Pushbroom Radiometer II
LAS	Landsat Assessment System
LDEF	Long Duration Exposure Facility
LIMS	Limb Infrared Monitor of the Stratosphere
LSI	Large Scale Integration
LTA	Lighter-than-air
LUT	Local User Terminal
MA	Multiple Access
MASEX	Marine Air-Sea Exchange Experiment
MEB	Main Electronics Box
MHD	Magnetohydrodynamic
MLA	Multispectral Linear Array
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Units
MOU	Memorandum of Understanding
MPP	Massively Parallel Processor
MSS	Multispectral Scanner
MST	Module Service Tools

NASA	National Aeronautics and Space Administration
NASCAD	NASA Computer-Aided Design
NASTRAN	NASA Structural Analysis
NEXUS	NASA Engineering Extendible Unified Software
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NSSC-1	NASA Standard Flight Computer
NSSDC	National Space Science Data Center
OETP	Orbiter Electron Temperature Probe
OSI	Open System Interconnection
PCDBMS	Pilot Climate Data Base Management System
PD	Partial Discharge
POCC	Project Operations Control Center
RAP	Regional Applications Program
R&D	Research and Development
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Remote Manipulator System
ROS	Research Optical Sensor
ROWS	Radar Ocean Wave Spectrum
SACC	Science and Applications Computer Center
SAMII	Stratospheric Aerosol Measurement Experiment
SARSAT	Search and Rescue Satellite-Aided Tracking Mission
SBAW	Shallow Bulk Acoustic Wave
SBUV	Solar Backscatter Ultraviolet
SCR	Surface Contour Radar
SEL	Software Engineering Laboratory
SI C&DH	Scientific Instrument Control and Data Handling
SIMB	Single Instruction Multiple Data
SMM	Solar Maximum Mission
SMMR	Scanning Multichannel Microwave Radiometer
SMRM	Solar Maximum Repair Mission
SOGS	Science Operations Ground System
SST	Sea Surface Temperature
ST	Space Telescope
STDN	Space Tracking and Data Networks
STOCC	Space Telescope Operations Control Center
STS	Space Transportation System
ST ScI	Space Telescope Science Institute

ACRONYMS (Continued)

TAE	Transportable Applications Executive
TDAS	Tracking and Data Acquisition System
TDRS	Tracking and Data Relay Satellite
TM	Thematic Mapper
TNT	Taurus-Nike Tomahawk
TOMS	Total Ozone Mapping Spectrometer
UARS	Upper Atmosphere Research Satellite
VAP	Verification and Acceptance Program
VAS	VISSR Atmospheric Sounder
VISSR	Visible Infrared Spin-Scan Radiometer
VLBI	Very Long Baseline Interferometer
VLSI	Very Large Scale Integrated
VMS	Vector Magnetometer Satellite
WF/PC	Wide Field Planetary Camera
WSMC	Western Space and Missile Center
XRP	X-ray Polychromator

NOTE

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